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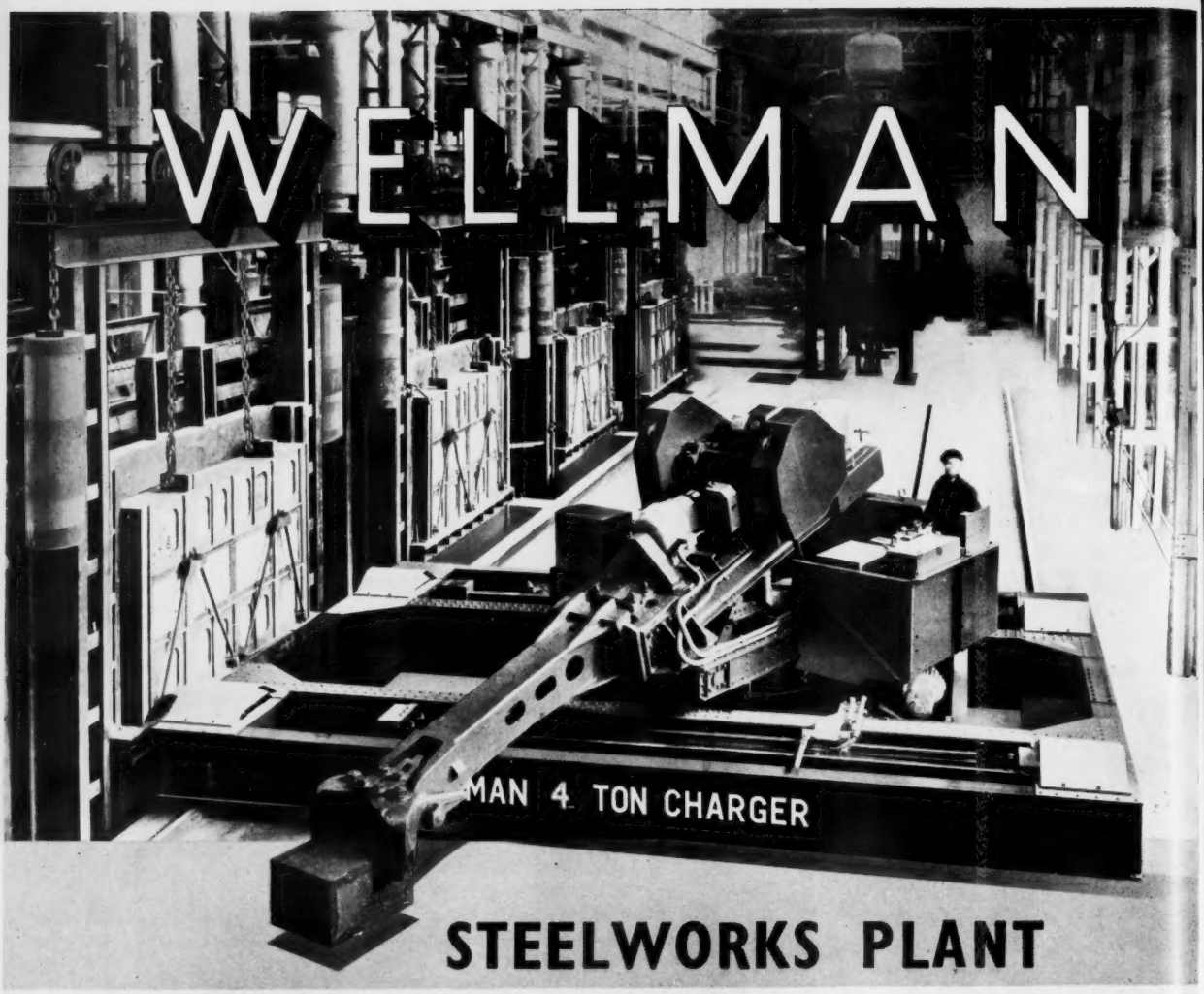

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WE DESIGN AND CONSTRUCT:

INGOT STRIPPERS

FURNACE CHARGING MACHINES — LADLE CRANES

SPECIAL STEELWORKS CRANES

AUXILIARY ROLLING MILL EQUIPMENT

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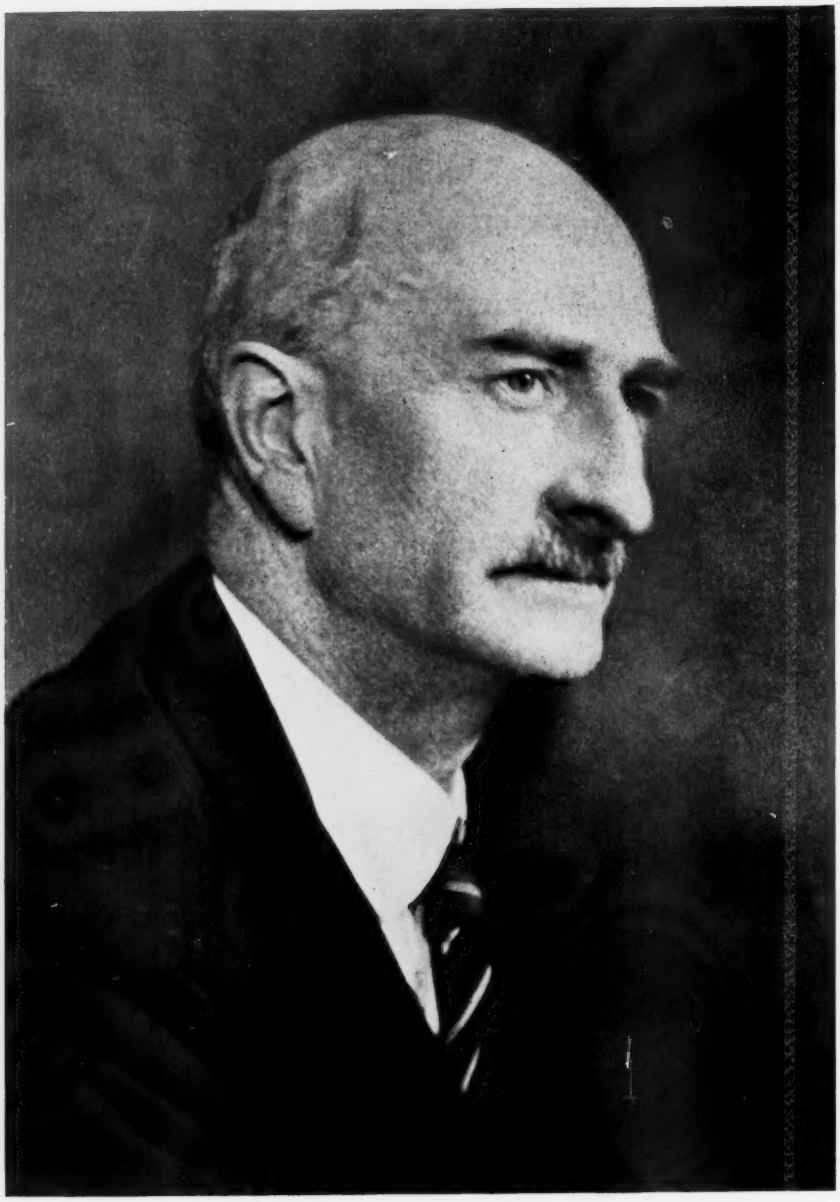
H. HICKS

HARRY HICKS was educated at St. Matthias' Church School, Sheffield, and commenced his career with J. J. Saville and Company, Limited, in 1905. He worked in various departments of the Company, gaining general experience, and in 1913 he took up an appointment as Assistant Steel Manager with Moses Eadon and Sons Limited In 1918 he joined John Bedford and Sons, Limited as Steel Manager. Two years later he was appointed Manager of the Steel Sales Department of John Holding and Company, Limited, a position which he held for nineteen years. During this time he took part-time courses at the Sheffield University Technical School in order to increase his technical knowledge.

In 1939, Mr. Hicks was appointed Assistant to the Managing Director of the Sheffield Forge and Rolling Mills Company, Limited, and in 1942 he became General Manager. He was made a Director of the Company in 1943, and about eighteen months later he was appointed Managing Director.

Mr. Hicks is a member of the Executive Committee of the Sheffield Rollers, Tilters, and Forging Association, and is one of three Sheffield representatives on the Executive Committee of the National Association of Independent Re-Rollers. He has been a member of the Sheffield Metallurgical Association for about seventeen years, and was elected President for the session 1953-54.



H. Hicks
Honorary Member of Council, 1953-54

SEVENTH HATFIELD MEMORIAL LECTURE

THE IRON AND STEEL INSTITUTE

Development in the Iron and Steel Industry in Great Britain During the Last Twenty-Five Years

By T. P. Colclough, C.B.E., D.Sc., M.Met., F.R.I.C.

SYNOPSIS

The features that characterize the development of the iron and steel industry during the last 25 years are reviewed. The experience gained in the 1920's resulted in the formulation of certain principles for the reconstruction of the industry, and it is shown how these were applied during 1930–1939. The war years demonstrated the soundness and economies of the pre-war projects and proved the benefits to be derived from the joint discussion and co-ordination of effort to solve common problems. The rapid and extensive development of the post-war years are outlined, and it is shown how productivity has improved during the period under review. Reference is made to some aspects of future development and the growing importance and influence of research is stressed. The essence of the development of the last 25 years has been the creation of a new spirit and unity within the industry. 976

Introduction

For those at present engaged in the steel industry, with all its activities and wide ramifications, it may sometimes be difficult to realize that the making of steel in bulk began less than 100 years ago and that this survey of development must cover one-quarter of the life of the industry.

In magnitude, the growth of production, in spite of temporary variations, has been remarkably steady and progressive, and there can be no doubt that as new needs arise and new uses are devised the industry will continue to grow. The tempo of growth may fluctuate, but the growth must be unceasing if the standard of life of the nation is even to be maintained, much less raised.

It is significant that no vital new principle for the making of iron or steel, or for the rolling and shaping of steel, has been discovered during this last quarter-century. The characteristic feature has been the application of scientific knowledge to the industry, based on an intensive study of the principles underlying the processes employed, with a resulting far greater knowledge and better understanding of the operations involved. On the one hand this has led to a marked improvement in the efficiency of the manufacturing processes themselves, a raising of the general standard of quality, and the development of many new types of steel with specialized properties. On the other hand, the inventive genius of the engineering section of the industry has been devoted to the application of scientific knowledge to the development of larger and more efficient units of production; the mechanization of plant with its reduction of manual labour; the greater use of electric power to replace steam as the source of energy and to replace raw fuel for melting and other purposes; and the development of instruments to give better control and greater precision to the manufacturing operations and, by reducing the dependence upon human judgment and reaction, to effect a remarkable increase in the speed and accuracy of operation. These developments have demanded and made

Delivered at the Royal Institution, Albemarle Street, London, W.1, on Wednesday, 26th May, 1954.

Dr. Colclough is Technical Adviser to the British Iron and Steel Federation.

possible a complete change in both the general lay-out and detail of the manufacturing operations, and this in turn has demanded considerable and important changes in the commercial and administrative organization. It may be of interest to mention briefly a few salient examples of the changes which have taken place.

In 1929 there were roughly 400 blast-furnaces in existence in this country. About one-half, or 200 furnaces, had an average capacity of 400 tons per week—totalling together a capacity of, say, 80,000 tons per week. To-day, eight operating furnaces have a capacity of over 50,000 tons per week, and when four other furnaces, at present under construction, come into operation the 12 furnaces are scheduled to produce 83,000 tons per week.

In steelmaking, the production per open-hearth furnace year has more than doubled, rising from 15,000 tons in 1929 to 39,000 tons in 1953. Electric furnace capacity has risen from about 100,000 tons to over one million tons per year.

In the rolling mills, the growth in number and capacity of the continuous mills has been phenomenal and the capacity of the latest primary rolling units recently brought into operation is roughly four times that of their corresponding units in 1929.

The target for production, three years hence, is 15 million tons of pig iron, practically double that of 1929, and roughly 20·5 million ingot tons of steel, an increase of more than 110% on 1929, which was at that time an all-time record.

That is the general picture; the sequence of events will now be examined a little more closely.

CONDITIONS IN YEARS 1920–29

The years 1920–29 marked one of the most difficult periods in the history of the industry. The artificial demand of the war years 1914–18 had seen the installation of steelmaking and rolling plant far in excess of the normal growth of requirements. Much of the new plant had been built to meet the emergency conditions at relatively high capital cost and was unsuited for normal commercial requirements. In addition, many old units of production, which normally would have been due for scrapping, were retained. As a result of the financial, economic, and industrial conditions after the war, the demand for steel fell away and many plants were either closed down or operated below capacity.

The realistic capacity of the blast-furnaces existing in 1920 may be assessed at about 10–11 million tons. The production during the ten years 1920–29 averaged only 6 million tons, or even omitting the two years of prolonged strikes, 6·87 million tons—not more than 60% of capacity.

In the steelmaking plants, the capacity in 1920 may be estimated at about 12 million tons, whilst the average production over the ten years was only 7·36 million tons, or again roughly 60% of capacity. The position was aggravated by severe competition from the Continent, particularly during the second half of this period. A large amount of new plant was installed in Western Europe, fostered by reparations and American investment, and the surplus output from these new plants was dumped in Britain.

During this 10-year period the imports of steel averaged 2·08 million tons per year, or the equivalent of about 2·6 million tons of ingots. It may be estimated that, in spite of the general state of industrial depression in this country as a whole, the demand for steel averaged about 9·9 million tons per year, but of this amount only 7·36 million tons per year were actually made in this country—26% of the steel required was imported. During the five years 1925–29, the total steel imported was roughly 3 million tons per year, and of this over 1·5 million tons were in the form of semi-finished steel, wire rod, or strip, mainly used for tube making. The salient facts were:

(i) Much of the existing plant was old and obsolete
(ii) Not more than 75% of the steel requirements was being made in this country
(iii) About 50% of the steel imported was in the semi-finished form.

The struggle for survival compelled a drastic revision of the financial structure of many companies; the scrapping of old, obsolete plants; and the closing of some works. Above all, it led to an intensive study of the methods by which plant and processes could be improved, operating costs lowered, and general efficiency raised so as to provide a sound financial basis for reconstruction.

As is well known, the decision was made that it was imperative to place the steel industry on a sound economic basis. To this end it was determined that new plant must be installed; the industry must be re-organized to establish operating units of economic size; the imports of steel must be controlled, to prevent the unfair competition from abroad; and facilities should be created to provide at reasonable rates the financial resources necessary for the reconstruction projects.

The steps taken to accomplish the provision of financial resources and the re-organization of the industry as a whole are not within the scope of this review; attention can be given only to the progress made within the industry.

RECONSTRUCTION

From the practical aspect, the last twenty-five years fall naturally into three divisions—the pre-war, war, and post-war years.

The ten years 1930–39 can be regarded as a period of experiment and tentative progress, the war years were perforce relatively static, and the post-war years have marked a period of rapid and extensive development based on the knowledge and experience gained in the earlier stages.

The Pre-War Years (1929–39)

The experience gained in this country and abroad during the years 1920–29 had demonstrated clearly the inherent advantages of integrated operation.

The transfer of metal from one operation to the next while still in the liquid or hot condition made possible marked reductions in the cost of fuel and inter-departmental transport. The close association of coke- and iron-making gave a wider field of application of the valuable coke-oven and blast-furnace gases to the steelworks operations, thereby reducing the

demand for raw coal and replacing it by a fuel which could be more readily controlled and more efficiently used.

As a result, certain principles were formulated as a basis for the reconstruction programme. These were:

(i) The new plants should, wherever practicable, be integrated from raw coal and iron ore to the production of rails, heavy sections, plates, and semi-finished steel

(ii) Coke and pig iron production should be centralized; the use of blended coal mixtures for coke making should be extended and the new coke ovens should be designed for under-firing with blast-furnace gas

(iii) Blast-furnace practice should be improved by the grading of the ores and sintering of the fines

(iv) Pig iron production should be assured a sound long-term basis by consolidation of the available home ore reserves

(v) Steelmaking and rolling operations should be concentrated to the point at which the production would be adequate for large-scale, low-cost operation

(vi) The operations of the primary steelmakers should be extended by the acquisition of certain re-rolling or finishing operations, so as to complete the integration of operations and provide an assured outlet for capacity production direct to the final customer

(vii) In determining the location of improvements or new installations, special regard should be paid to the freight costs involved in the assembly of the raw materials used and in the despatch to market of the finished products.

These principles furnished the fundamental bases for the modernization of the industry.

What were the steps taken to implement these principles ?

Whilst it is clearly impossible to give a detailed account of the many developments that occurred in the ten pre-war years, it is possible to select a few which illustrate the manner in which these principles were applied.

Lancashire Steel Corporation

The first of these deals with the position in South Lancashire, one of the centres of wire production. In this area there were blast-furnace plants, steelmakers, re-rolling plants, wire drawers, and wire fabricators, in total a substantial tonnage; but the different industries were almost totally unco-ordinated and the wire industry in a large measure relied on imports. The economic position of the iron and steel works was definitely unsound, and reconstruction of the production units was imperative. To provide a sound basis for reconstruction, it was decided to co-ordinate these industries into a single corporate body—The Lancashire Steel Corporation. The manufacture of pig iron and ferro-alloys was concentrated in the blast-furnaces at Irlam, which were furnished with a new dock, rapid unloading equipment, ore storage yard, and ore crusher. New gas-cleaning equipment was installed at the blast-furnaces, and new coke ovens designed to operate on blast-furnace gas were installed. The steel plant was rebuilt, embodying furnaces of new design with more rapid operation and equipped for the use of mixed gas and liquid fuel. A new continuous rod mill of the latest design was installed at Irlam for the re-rolling of their own billets; the wire rod was transferred to the nearby wire industry at Warrington. This development represented not only the integration of the iron and steel operations, but a complete integration from the raw materials, coal and iron ore, to the finished end product of wire and wire product.

This plant is now in process of being expanded in capacity by about 50%.

Guest, Keen Nettlefolds and Guest Keen Baldwins

Similarly, a number of isolated iron and steel works in South Wales and Scunthorpe were integrated with users of semi-finished steel in South Wales and Birmingham to form the two companies, Guest, Keen, and Nettlefolds Ltd. and Guest Keen Baldwins. Their iron and steelmaking operations in South Wales were concentrated in the works at Port Talbot and in a new plant at Cardiff. The latter plant comprised a completely integrated manufacturing unit of ore unloading docks, coke ovens, blast-furnaces, steel furnaces, continuous billet mill, and continuous bar, strip, and wire rod mills, together with a mill for the re-rolling of sections suitable for colliery arches, etc.

This plant, designed for a nominal production of 7000 tons per week, has since the war made and rolled over 15,000 tons of ingots per week and has made the two Companies largely self-contained in regard to their steel requirements in these forms.

Stewarts and Lloyds

A third example illustrates another form of plant and company integration. In 1929 the making of steel tubes was carried out by a large number of relatively small, widely scattered companies who relied to a marked extent on tube strip imported from the Continent. After a thorough examination of the possibilities, Stewarts and Lloyds decided to concentrate certain sections of their manufacturing operations in a new plant to be erected at Corby, completely integrated from ore and coal to finished tube. This project involved a combination of new principles, which may be briefly summarized as follows.

It was necessary to establish the first steelmaking operation on the Midland ore body, this ore previously having been regarded as unfavourable, when used alone, for the making of basic iron. Ore mining was organized on a scale hitherto unknown in this area and was equipped with, at that time, the largest ore stripper in the world. The small blast-furnaces were replaced by four new furnaces, up to 20-ft. hearth dia. —larger than it was generally considered possible to operate on Northamptonshire burdens. The whole of the ore was thoroughly graded and the fines were sintered before charging. Coke ovens were installed to provide the necessary coke, and the coals were blended to give the type of coke required.

The whole of the pig iron made was desulphurized before being used for steelmaking. For steelmaking the basic Bessemer process, which had gone out of use in 1925, was revived. The rolling mills comprised a semi-continuous slab and billet mill, a semi-continuous and a fully continuous mill for the

rolling of tube strip. The tube mills included a new 40-ft. seamless pipe mill and a new innovation, the rolling of butt-welded pipe by a fully continuous process.

Simultaneously with the erection of the new plant, the Company pursued a policy of commercial amalgamation with a number of other tube-making concerns, so as to give a fully economic load to the new plant and to provide an organization capable of handling and marketing the whole of the output of the integrated operation.

Richard Thomas and Co. and John Summers and Sons

The fourth example deals with another facet of this many-sided problem—a completely new manufacturing process. In the U.S.A. the 1920's were a period of marked development in the installation of continuous mills for the hot-rolling of strip, and this was followed by the discovery that, given sufficient power and speed, steel strip in the form of coils could be reduced cold in continuous mills. This led to the installation of continuous mills for the hot-rolling of slabs into coils of strip and the cold-reduction of the strip to sheet and tinplate gauges.

It became apparent that if Britain was to maintain her position as a manufacturer of these products it was essential to adopt this new process, and it was decided by Richard Thomas and Co., Ltd., to erect a completely new integrated plant on the site of the old works at Ebbw Vale for the manufacture of sheet and tinplate, and in particular to meet the requirements of the motor-car industry for car body sheets.

Shortly afterwards, John Summers and Sons installed a semi-continuous mill for the hot-rolling of coiled strip and a fully continuous mill for cold-reduction to sheet gauges, in conjunction with their cold-metal melting shops at Shotton.

United Steel Companies

The last type which can be dealt with in this brief survey may be illustrated by the development of the United Steel Companies. This group, with its associates, was formed to consolidate a wide range of manufacturing interests and products. The Company was a pioneer in many directions, and their development programme dates back to the first-war period. The overriding feature may be regarded as the concentration of the different types of product into cognate groups suitable for production in one plant. Rail production is concentrated at Workington; plates and heavy sections at Appleby-Frodingham; billets, strip, and bars at Templeborough; heavy forgings and the related products, wheels and tyres, at Rotherham; and alloy and special steel production at Stocksbridge. Each works is confined to the production of a definite range or type of product, and in each case the design of the works is on the scale which will give a productive capacity adequate to justify the capital expenditure that is required to provide the modern equipment installed.

This record of initiative and enterprise for the years 1929–39 is probably without parallel in the history of the industry, and the success achieved by these courageous but well-based projects gave a sound foundation and pattern for the forward policy of the post-war years.

The halt imposed on new building by the war conditions was probably of immense value, for it gave an opportunity to prove by experience the relative merits of the different types of development.

The War Years

Development during the war years 1939–44 showed quite a different pattern from that in the years 1914–18. In the first war, steel productive capacity was expanded as rapidly as possible and, as is well known, led to considerable difficulties in post-war years. In the second war it was, for several reasons, deemed expedient to concentrate efforts in this country on the production of vital steels and to provide all possible expansion overseas.

The first obvious result was that, whereas the overall steel production in the U.K. in 1918 was 1·87 million tons (or 24%) higher than in 1913, the maximum steel production during the second war was never substantially above that of the peak pre-war year, 1937.

On the other hand, there was a marked change in the pattern of the quality of steel made. This is demonstrated by two salient factors—the development of electric furnace production and the increased production of alloy steel. In the years 1937–38 the production of electric steel averaged about 220,000 tons, or 1·9% of the total steel made. This rose to a peak tonnage in 1943 of 990,000 tons, or 7·5% of the total production—a fourfold increase.

In addition, a marked contribution to the war effort was made by the change-over of several of the open-hearth steelmakers from ordinary commercial qualities to the manufacture of alloy and special steels. The production of alloy steels rose in 1943 to a peak figure of 1·6 million tons, or over 12% of the total steel production.

Mere figures, however, are totally inadequate to present the true picture of the real development which British technical men and operators made in regard to quality during this period, and still fully maintain. This work placed Britain in a pre-eminent position in the manufacture of the highest qualities of steel, and it is to be hoped that the full story will be placed on record by a competent authority.

Probably the two most important factors emerging from the war years were: (*a*) the experience of these years demonstrated the soundness and economies of the pre-war projects and provided a solid foundation for further developments, and (*b*) the co-operative efforts imposed by war conditions proved the necessity for, and benefits to be derived from, joint discussion and co-ordination of effort to solve the common problems. This second factor applied particularly to the need for ensuring adequate supplies and correct distribution of the essential raw materials, which led to the establishment of a central body for the purchase and distribution of imported ore and the strengthening of the organization built up before the war for the control of the scrap and steel required to fill the gaps in the home market. It was also advisable further to improve the arrangements made in the pre-war

Table I

BLAST-FURNACE DEVELOPMENT, 1929–1954

Figures in parentheses denote percentages based on 1929

Quantity	1929	1937–38	1945	1953
Number of blast-furnace plants	88	57	53	44
Furnaces in existence	394	200	168	137
Average number in blast	158·25	111·5 (70·4%)	99·2 (62·7%)	104·7 (66·1%)
Blast-furnace production, thousand tons	7589	7627 (105%)	7107 (94%)	11,175 (147%)
Annual production per operating furnace, tons	47,960	68,550 (143%)	71,640 (149%)	106,700 (222%)

period for the joint examination of the development programmes of individual companies in the light of probable market demands, to ensure that estimated requirements would be met in the most economic manner, and, at the same time, to avoid unnecessary capital expenditure and wasteful competition.

The Post-War Years

Before the end of the war, discussions were initiated for the preparation of an agreed development programme. The principles underlying this forward policy and its broad outlines were agreed by December, 1945, and were published in the Command Paper of May, 1946. This document is too familiar to need recapitulation, but it may be of interest to review briefly how far and in what manner the objects set forth in that programme have been attained.

The primary objects of the Five-Year Plan, of which the principal projects were to be initiated by 1951 and completed by 1953, were:

(*a*) To increase steel production to about 15 million tons per year—an increase of 3 million tons (or 25%) over the pre-war maximum of 1937

(*b*) To install about 5 million tons of iron and steel-making plant of modern, efficient design

(*c*) To install the most efficient design of rolling mills

(*d*) To consolidate production in units of economic capacity and embodying the most recent methods of manufacture.

POST-WAR PRODUCTION

The production target of 15 million ingot tons was achieved by 1949 and has been surpassed in each succeeding year. It was soon recognized that the target figure, optimistic as it appeared at the time, was not adequate to meet the growing demands of the country. After discussion with the Government Departments concerned, it was agreed that the target should be raised to 18 million ingot tons, to be achieved by the mid-1950's. In every year except 1951, when there was a sharp fall in receipts of imported scrap, there has been a substantial increase in production. The production for 1953 was 17·6 million tons, and the present target is for a production of about 20·5 million tons in the years 1957–8.

Pig Iron Production

The first essential for steel production is an adequate supply of pig iron, and special attention has been given to this section of the industry.

The production from the blast-furnaces in 1953 totalled 11·2 million tons, an increase of 47% on the 1929 production. This has been achieved by a ruthless elimination of obsolete plant, a concentration of production in fewer works, a gradual but steady increase of size of furnace, and the wider application of burden preparation to improve the operating conditions within the furnace. The progress made is summarized in Table I.

The most significant factor is the increase in production per furnace operating, from 48,000 tons in 1929 to 107,000 tons in 1953; this increase is even greater if basic iron furnaces alone are considered. The outstanding feature is the growth in size of the furnace. The first ten years saw the experimental development from the maximum size of 15–17-ft. hearth dia. furnace to the 22-ft. hearth dia. of the two new furnaces of 1938 at Appleby-Frodingham. Since the war, these two furnaces have been expanded to 25 ft. dia.

To-day, six furnaces of 25–28 ft. hearth dia. are operating and six furnaces of 27–29 ft. hearth dia. are in course of construction.

It is estimated that the target production of 15 million tons of iron in 1958 will be achieved by the operation of not more than 107 blast-furnaces—an average of about 140,000 tons per furnace year, but with 12 furnaces of recent construction averaging 350,000 tons per furnace.

It is not to be expected that there will be a further marked increase in blast-furnace size in the near future. It is well established that the percentage effective hearth area diminishes as the actual size increases, and it is the general opinion that the optimum size has now been reached for present operating conditions.

The second dominating factor has been the growth of the ore preparation plants. Special attention may also be directed to the value of the ' bedding ' plants installed at two works to secure a uniform composition of ore for charging into the furnace. The crushing and grading of the ore and the sintering of the ore fines

Table II

SINTER PLANTS IN U.K.

Installed	Nominal Capacity, tons × 10^3	Production in 1953, tons × 10^3
Before 1929	120	77·1
1929–39	3441	2850·1
1940–53	2247	1806·9
Total to 1953	5808	4734·1
Projected 1954	4000	
Total to end of 1954	9808	

Estimated production 1955: 8½–9 million tons

are now accepted as essential for the economic operation of the blast-furnace. The growth of this practice from practically nil in 1929 to about 9 million tons of sinter capacity for the current year is shown in Table II.

The beneficial effect of this treatment of the ore has been fully discussed at the recent Symposium on Sinter and needs no further elaboration. The extent to which the principle of sintering the ore before charging into the furnace can be applied to different types of ore and blast-furnace practice with increasing economy is still subject to examination.

It may well be that further investigations of this problem and the application of oxygen and/or higher furnace pressure operations may lead to modification of the present opinion on the optimum size of furnace.

Steelmaking

The principal features of the steelmaking development have been the increasing dominance of the basic open-hearth process and a marked replacement of acid open-hearth production by electric furnaces, together with the re-introduction of the basic Bessemer process in two special cases.

The distribution of production by various processes is given in Table III, which shows that the production of basic open-hearth steel has doubled in the period under review and that 97% of the total increase in tonnage was made by this process.

As in blast-furnace development, the increased production of open-hearth steel has been achieved by a reduction of the number of furnaces installed, the replacement of small units by furnaces of greater capacity, and a marked increase in the production per furnace employed.

Table IV shows that, while the number of furnaces installed has decreased from 595 to 397, the average size of furnace has increased from 55 tons to 95 tons per charge and the production per furnace year from 15,000 tons to 38,870 tons. The development of integrated plants has increased the use of the hot-metal process, and in 1953 practically 80% of the basic pig iron made was used for steelmaking in the liquid state.

Tilting furnaces have been increased in number and in size from 150 tons to the latest nominal 400 tons per charge. Hot-metal fixed furnaces are now of up to 200 tons capacity and cold-metal furnaces range up to 150 tons.

Apart from mere size and increased proportion of hot metal, marked improvements have been made in design, charging facilities, and particularly in the application of oil fuel and the instrumentation to facilitate increased speed of operation and automatic control.

The electric furnace process, which was in its infancy in 1929, now gives a production of over 1 million tons per year, and individual furnaces of up to 60 tons capacity are under construction. The use of coke-fired crucible furnaces has been almost entirely superseded by the new design of electric induction furnaces.

As stated earlier, new installations have revived the basic Bessemer process and production has approached 900,000 tons. It is probable that with the new arrangements for blowing with oxygen, with or without steam or CO_2, the production and quality of this type of steel may show marked developments.

Rolling Mills

Unfortunately, the lack of statistical data will not permit the same type of assessment of rolling mill development. Nevertheless, this development is real. The striking feature is the increased application of electric drive and of continuous mills, the value of which had been so fully demonstrated before 1929 in the collection of mills at Templeborough.

Table III

PRODUCTION OF STEEL BY VARIOUS PROCESSES

Process	1929		1939		1953	
	tons × 10^3	% of total	tons × 10^3	% of total	tons × 10^3	% of total
Bessemer: Acid	559	5·8	233	1·8	263	1·5
Basic	Nil	...	701	5·3	798	4·5
Open-hearth: Acid	2451	25·4	2157	16·3	1133	6·4
Basic	6488	67·4	9705	73·4	14,298	81·2
Electric	87	0·9	292	2·2	929	5·3
Other	51	0·5	133	1·0	188	1·1
Total	9636	100·0	13,221	100·0	17,609	100·0

Primary mills with a capacity of up to 45,000 tons of ingots per week have been installed, and continuous billet mills with rolling capacity of up to 20,000 tons per week have replaced many of the old reversing type mills with a maximum of about 7000 tons per week.

In the heavy structural and rail mills there has been a marked concentration of production, and the proposed continuous beam mill is under construction. Four-high plate mills have been installed for the more accurate rolling of plates, particularly of medium and light thicknesses.

In regard to re-rolling, the new continuous mills for the rolling of wire rods are fully adequate to meet the requirements of the wire industry and to provide the material, in coils, required for the new processes developed for the manufacture of nuts, bolts, and rivets. A complete revolution has been effected in these industries.

A striking innovation has been made by the introduction of the Sendzimir cold-reduction mills for strip of special quality or heavy reductions to thin gauges. The most recent introduction of the Sendzimir hot-rolling or planetary mill is still in the development stage.

New continuous mills for the hot and cold rolling of strip, and increased supplies of steel in more highly finished form, have stimulated the growth of new cold-forming industries, and here, also, marked expansion and developments may be anticipated.

The outstanding feature in the rolling mill section is, of course, the development of continuous mills for the hot and cold rolling of sheets and tinplates. The pioneer installation at Ebbw Vale, with a designed capacity of 500,000 tons per year, represented a complete revolution in the manufacturing process—integration from ore and coal to finished product. The success of this project is apparent and the plant is in process of expansion to 1 million ingot tons per year. The second unit, at Shotton, was first installed in conjunction with the cold-melting shop, and since the war the plant has been converted into a fully integrated unit and the capacity is also being increased to over 1 million ingot tons.

The third unit, the largest, with a completely integrated operation up to the hot-rolling stage of plates and coils at Port Talbot, and cold-reduction units at Llanelly, Port Talbot, and Newport, is already producing at the rate of 1·5 million ingot tons and is in process of expansion to a capacity of 2·25 million tons. With the completion of these expansion schemes it is estimated that the requirements of the sheet and tinplate market will be fully met by the modern units and that there will be surplus production available as plates or coils for further processing.

RESEARCH

No survey of the developments of this period, however inadequate, could fail to refer to the growing importance and influence of research. Development in this field owes much to the efforts and example of the late Dr. Hatfield, to whose memory tribute is paid to-day. The activating force in his valuable work was not solely an endeavour to discover new facts or new steels, but was primarily the application of scientific facts and the scientific method to the study of works' problems, and to give a sound, fundamental basis to the different manufacturing operations and processes.

To-day, this is recognized to be a necessary function of every operating company. One of the most important developments of the period has been the increasing stress laid on the provision of adequate facilities within a works organization for the carrying out of research, technical supervision, and control of operation, and the technical training of personnel—both staff and operators—required for the successful operation of the powerful and sometimes complicated equipment now available.

There is, however, an even broader aspect. Early in his career, Dr. Hatfield recognized that no one company could deal adequately with the many problems demanding solution, and in 1924 he undertook the chairmanship of the committee set up by The Iron and Steel Institute for the study of ingot

Table IV

PATTERN OF OPEN-HEARTH FURNACE CAPACITY

Capacity, tons	1929			1953		
	Average Capacity, tons	No. of Furnaces	%	Average Capacity, tons	No. of Furnaces	%
<60	39·6	374	62·8	42·8	112	28·2
60–79	64·1	170	28·6	65·0	91	22·9
80–99	81·3	19	3·2	85·3	74	18·7
>100	166·0	32	5·4	171·0	120	30·2
Total		595	100·0		397	100·0

	1929	1953
Average capacity per charge, tons	54·7	94·5
Production during year, tons × 10^3	8939	15,431
Production per furnace year, tons	15,020	38,870
Average number of heats per furnace per year	274	411

structure. This was the real beginning, within the industry, of co-operative research.

Its value was recognized from the outset, and the experience gained during the war years by the research committees under Dr. Hatfield, Dr. Swinden, and others, demonstrated that this work must be established as a fundamental feature of the permanent structure of the industry. The establishment of the central Research Association, with its band of highly skilled investigators, examining both fundamental principles and works' problems, cannot fail to accelerate progress; and the opportunity which it affords within its structure for regular discussion, by the technical personnel of the works and the central staff, of mutual problems and new discoveries has already proved of inestimable value.

THE FUTURE

Although the subject of this review is development over the last twenty-five years, it will be appreciated that development is not a static process. To be effective, it must be activated by a continuous and definite policy, with due regard to both immediate requirements and long-term trends.

More than once some doubts have been expressed as to the wisdom of the expansion at present in hand. Not yet, however, has steel production attained the level at which the steel requirements of the country can be fully met. On the other hand, there can be no doubt that if this country is to maintain its economic stability, and if the demand for a higher standard of living both in this country and overseas is to be met, further expansion is imperative.

Competent authorities have estimated that, on the average, provision must be made for an increase of $2\frac{1}{2}\%$ per annum in British steel production. In the course of ten years this would amount to over 25%, and, taking the forward view, it is not unreasonable to suggest that the steel production of this country should be raised to about 25 million ingot tons by the middle 1960's. It is not to be anticipated that the increase will be uniform over all types of product. So far as can be visualized at the moment, there will be a more marked increase in the requirement of flat rolled products and bars and other forms required by the engineering industry.

This prospective increase raises the question of adequate supplies of raw materials. There can be no doubt that new resources of iron ore are available if development is put in hand. This additional ore, in general, is at somewhat greater distances from this country, and additional and improved forms of transport must be provided. For economy, it is essential that this ore shall be carried in the largest practicable type of ore carrier. It is urgent that steps should be taken immediately by the dock authorities for the further improvement of unloading facilities and the provision of berths for ships of deeper draught at at least four of our principal ore reception ports.

It is evident that the supply of suitable coal will present some difficulties. Here again, research should be concentrated on methods of attaining greater fuel economy, and a study should be made of the possible extension of the use of fuel oil for heating purposes in steelworks.

It will be agreed that one contributing factor to the overall problem is the relation between the steel and gas industries. If the total supply of coal suitable for carbonization is limited, it may well be desirable to consider a further extension of the transfer of coke-oven gas from the steel industry's ovens to the gas industry. The establishment of wider-spread gas grids could do much to lower the demand on the available coking coals and, subject to reasonable transfer prices, add to the general overall economy.

The location of this additional steelmaking capacity should be determined after careful examination of the vital factors of availability of labour and fuel and the freight costs of assembly of raw materials and despatch of product to market.

All that has been described so far represents merely the mechanism and form of the development. Statistics can never reveal the true man or his motive. The real essence of the development of the last twenty-five years is the creation of a new spirit and of a sense of unity within the industry which never existed previously. The discussion in common (at all levels) of individual difficulties and general problems, the sharing of individual discoveries, the joint formulation of requirements and the means to provide them, the readiness to help those in special difficulty, and the willingness to modify individual proposals in the light of the common need, are the factors which alone have made possible the achievement of the common objective and are the real essence of the progress made. So long as this spirit pervades the activities of the steel industry, there can be no question that the needs of the country will be met and the well-being of the industry ensured.

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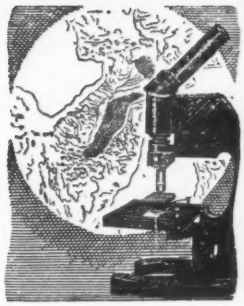

Anisothermal Decomposition of Austenite in a Medium-Alloy Steel

By P. T. Moore, Ph.D., B.Sc., D.I.C.

SYNOPSIS

Austenite decomposition occurring anisothermally has been studied by the 'step-quench' and continuous-cooling methods, with a view to checking the validity of the Scheil 'fractional nucleation' theory and its modifications. The results of the step-quench experiments show that little reliance can be placed on the theory for predicting the occurrence of such transformations, whereas the results of the continuous-cooling experiments show a much better correlation between calculated and observed progress of transformation. Possible uses for this correlation in transformations occurring during continuous cooling are indicated.

An explanation is put forward of the mechanism of the decomposition of austenite, based on the principles of varying rates of nucleation and growth, to assist in understanding the nature of phase transformations in general.

A brief review of the relevant published literature on the subject of austenite decomposition is also included.

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REVIEW OF LITERATURE

THE study of the decomposition of austenite and the products formed can be said to have begun with the studies of Carpenter and Robertson.[1]

Davenport and Bain[2] were the first workers to comment on the incubation period which elapses before supercooled austenite begins to break down, and to use the now familiar isothermal transformation diagram, or 'S-curve,' as a means of setting out isothermal test results.

A theory, called the 'fractional-nucleation' theory, was advanced by Scheil[3] and later, independently, by Shteinberg,[4] to predict the start of transformation under non-isothermal conditions. This theory was taken as a basis for much of the present work.

If the incubation period at temperature $T°$ C. is t sec., a specimen held at this temperature for a period of t_1 sec. (where t_1 is less than t) may be said to have undergone a fractional nucleation of t_1/t. This is also the Scheil fraction for this particular condition.

It was postulated by Scheil that a thermal treatment corresponding to a sum of all the fractions equal to unity will bring the steel to the point of commencement of austenite decomposition. This may be applied to an infinite number of separate Scheil fractions, corresponding to continuous cooling conditions, the expression then being

$$\sum_{T_0}^{T_e} \frac{t_1}{t} = 1.$$

By the use of this expression, the time and temperature at which transformation should start may be calculated from a knowledge of the time/temperature curve followed by the specimen during cooling. The summation begins at temperature T_e, at which the austenite becomes supercooled, and is continued until the fractional sum reaches unity at some temperature T_0. It was believed that the Scheil theory might prove useful for the prediction of transformation on cooling in large forgings or other parts cooling freely in air.

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Dr. Moore is now with I.C.I. Ltd., Billingham Division.

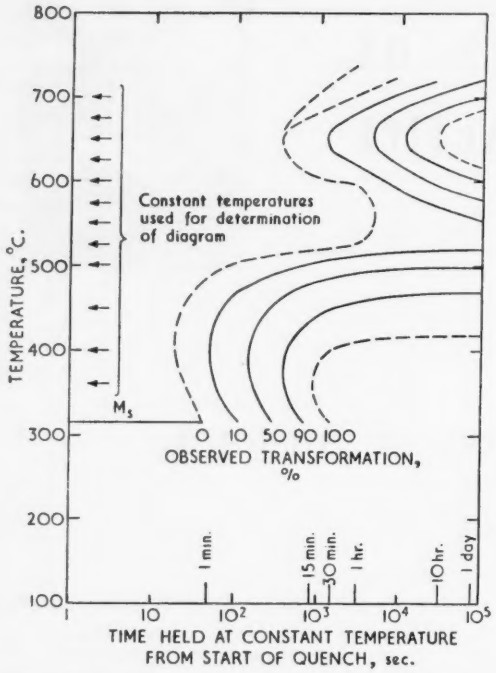

Fig. 1—Isothermal transformation diagram, as determined by microscopical examination

Reference to step-quenching has been made by Liedholm,[5] Manning and Lorig,[6] and Hollomon and Jaffe,[7] but in all cases the experiments have been carried out to determine the effect of a small amount of transformation at one temperature on transformation at a second temperature.

In attempting to correlate transformations on cooling, such as normally occur in practice, with isothermal transformations, which are more easily studied in the laboratory, the method of Pumphrey and Jones[8] must be mentioned. In their paper they set out the method of calculating the time for the start of transformation under known cooling conditions from Scheil's hypothesis. This method has been adopted for the continuous-cooling experiments described in this paper.

No previous work appears to have been carried out on the effect of ' partial nucleation ' (*i.e.*, holding for a known fraction of the incubation period) at one temperature on transformation at a second temperature.

Despite its complex composition, the En 24 type of steel was selected for this investigation because of the clear separation between the temperature ranges of pearlite and bainite formation, and the formation of pro-eutectoid ferrite at higher temperatures in the pearlite range shown by the isothermal diagram.

THE ISOTHERMAL TRANSFORMATION DIAGRAM

Previous workers have suggested, and the present author's experience confirms, that the method of microscopic examination of heat-treated specimens, although more tedious, is likely to be more accurate than the dilatometric method for the determination of the isothermal transformation characteristics of a steel. The isothermal diagram was therefore determined by the microscopic examination of quenched specimens. It is shown in Fig. 1. The results of these determinations are in reasonable accord with those for the same steel, published in the Atlas of Isothermal Transformation Diagrams.[9]

The average chemical analysis of the steel used for the experimental work was as follows:

C, %	Si, %	Mn, %	S, %	P, %	Ni, %	Cr, %	Mo, %
0·38	0·26	0·70	0·013	0·015	1·63	0·98	0·22

The grain size of the cold-rolled wire and tape used to form test specimens was fine, but banding was clearly visible in the tape.

STEP-QUENCH EXPERIMENTS

Procedure

The step-quench experiments were carried out by the following method. Groups of six tape specimens were clasped in a specially designed jig, so that identical heat-treatment was given to all the specimens. The specimens were subjected to a standard austenitizing treatment followed by immersion in a lead bath held at the first controlled temperature. After being held in this bath for a predetermined fraction of the appropriate incubation period, they were rapidly transferred to the second lead bath, and held at the second controlled temperature. Individual specimens were removed at calculated times and quenched in water. The approximate time at which transformation began could be obtained by microscopic examination. On the basis of these results a second set of specimens was given similar treatment, to determine the time more accurately.

Experiments of this type were carried out at fixed temperature intervals from 700° to 360° C. (the range through which the transformation was plotted), specimens being quenched in turn from each selected temperature in the range to every temperature below it. Table I indicates the temperatures used and the change in structure obtained with each set of specimens. Each experiment in this range was repeated at least twice to check the reproducibility of the results obtained. In all but a few cases the reproducibility was excellent, and in every case the results recorded are those obtained from at least two corresponding heat-treatments. At each pair of tempera-

Table I

TEMPERATURE CONDITIONS AND STRUCTURAL CHANGES OF SPECIMENS

Structure at Upper Temp.	Structure at Lower Temp.	Upper Temp., °C.	Lower Temp., °C.
Ferrite	Ferrite	700, 675, 650	675, 650
Ferrite	Pearlite	700, 675, 650	625, 600, 575
Ferrite	Bainite	700, 675, 650	500, 450, 400, 360
Pearlite	Pearlite	625, 600, 575	600, 575
Pearlite	Bainite	625, 600, 575	500, 450, 400, 360
Bainite	Bainite	500, 450, 400	450, 400, 360

tures considered, experiments were carried out using 25%, 50%, and 75% of the incubation period as holding times at the upper temperature. There are 45 pairs of heat-treatment at the temperatures shown.

Discussion of Results

For the purposes of this discussion the results for any given pair of temperatures may fall into any one of the following three classes:

(A) Results in which all the total fractions are less than 100%

(B) Results in which the total fractions approximate nearly enough to a value of 100% for it to be said that the transformation has occurred in accordance with the Scheil hypothesis

(C) Results in which all the total fractions are greater than 100%.

Table II shows that out of 45 pairs of temperatures, only eight yielded results in class *B*. It may therefore be concluded that this steel does not normally comply with the hypothesis, when subjected to a two-temperature heat-treatment.

Experimental results were considered to fall into class *B* when the total fractions obtained were all between 90 and 110%. Thus a 10% allowance has been made for experimental error. This allows for cases where a short soaking time in one or both of the lead baths is involved; an error of 1 sec. may correspond to an overall error of several per cent.

Table II

SUMMARY OF RESULTS OF STEP-QUENCH EXPERIMENTS

Test Series	Range in which Nucleation was		Soaking Temp., °C.		Total Scheil Fraction After Known Percentage Nucleation at First Temp., %			Class of Result
	Initiated	Completed	First	Second	25% Nucleation	50% Nucleation	75% Nucleation	
1	Ferrite	Ferrite	700	675	87	88	91	A
2	,,	,,	,,	650	94	89	93	A
3	,,	,,	675	,,	85	83	92	A
4	Pearlite	Pearlite	625	600	103	103	102	B
5	,,	,,	,,	575	82	93	95	A
6	,,	,,	600	,,	69	75	88	A
7	Bainite	Bainite	500	450	107	100	100	B
8	,,	,,	,,	400	61	79	96	A
9	,,	,,	,,	360	67	81	97	A
10	,,	,,	450	400	68	79	86	A
11	,,	,,	,,	360	69	75	92	A
12	,,	,,	400	,,	75	75	88	A
13	Ferrite	Pearlite	700	625	81	90	111	...
14	,,	,,	,,	600	114	113	97	C
15	,,	,,	,,	575	112	116	112	C
16	,,	,,	675	625	113	122	115	C
17	,,	,,	,,	600	119	127	122	C
18	,,	,,	,,	575	97	108	120	C
19	,,	,,	650	625	117	126	115	C
20	,,	,,	,,	600	104	103	103	B
21	,,	,,	,,	575	62	74	88	A
22	Ferrite	Bainite	700	500	104	109	106	B
23	,,	,,	,,	450	121	121	112	C
24	,,	,,	,,	400	82	89	95	A
25	,,	,,	,,	360	53	72	86	A
26	,,	,,	675	500	60	81	97	A
27	,,	,,	,,	450	104	100	100	B
28	,,	,,	,,	400	79	82	89	A
29	Ferrite	Bainite	675	360	36	56	81	A
30	,,	,,	650	500	78	82	92	A
31	,,	,,	,,	450	100	92	96	B
32	,,	,,	,,	400	114	118	136	C
33	,,	,,	,,	360	100	100	100	B
34	Pearlite	Bainite	625	500	110	110	116	C
35	,,	,,	,,	450	121	123	125	C
36	,,	,,	,,	400	114	100	89	...
37	,,	,,	,,	360	122	139	139	C
38	,,	,,	600	500	78	90	107	...
39	,,	,,	,,	450	104	101	108	B
40	,,	,,	,,	400	103	68	82	A
41	,,	,,	,,	360	114	119	121	C
42	,,	,,	575	500	99	117	134	C
43	,,	,,	,,	450	125	141	137	C
44	,,	,,	,,	400	107	121	132	C
45	,,	,,	,,	360	119	138	144	C

Even if this experimental error is taken into account, most of the results show graphs which do not approach the ' ideal ' straight line, fractions as diverse as 36% and 144% being obtained. In general, therefore, the Scheil hypothesis cannot be relied on for the prediction of the time at which anisothermal transformation (*i.e.*, transformation occurring after treatment at two or more temperatures) will begin.

The total fraction is less than 100% in most cases in which both temperatures are in the range where ferrite is the nucleating constituent, *i.e.*, where ferrite or bainite is the first product to form isothermally. This applies to experiments 1–3, completely within the temperature range of pro-eutectoid ferrite formation; experiments 7–12, completely within the range of bainite formation; and experiments 22–33, where nucleation was initiated in the ferrite range and completed in the bainite range.

It therefore appears that any given percentage of the incubation period spent at the upper temperature is equivalent to a greater percentage of the incubation period at the lower temperature. This is believed to be due to the difference in the critical size of the ferrite nuclei at the two temperatures concerned. Thus, a partly developed nucleus at, say, 700° C. might correspond to an almost fully developed nucleus at, say, 650° C. Also a ' nucleus ' which exists, but which is smaller than the critical size, at 700° C. (and therefore by the laws of thermodynamics, should shrink and disappear), may, without growth, be larger than the new critical size at 650° C., and thus become an effective agent for the nucleation of the transformation product. Both these possibilities will combine to produce total Scheil fractions less than 100% in such cases.

Exactly the same considerations will apply to experiments where nucleation is both initiated and completed in the temperature range of carbide nucleation, *i.e.*, of pearlite formation, and experiments 4–6 showed that total Scheil fractions less than 100% did in general result from these tests.

By contrast, experiments in which nucleation was initiated in the ferrite range and completed in the pearlite range (13–21), or initiated in the pearlite range and completed in the bainite range (34–45), show a general tendency towards results in class *C*, *i.e.*, with total Scheil fractions greater than 100%. In these cases, the formation of the second type of nucleus, required for the eventual transformation, is retarded by previous holding in the range where the opposing type of nucleus is normally formed, as was suggested by Manning and Lorig.[6]

This is likely to be caused by the occupation of the most favourable sites for nucleation by the first type of nucleus; greater energy is thus required for the formation of nuclei at the second temperature. Zener[10] has shown that the favourable sites will be mainly at austenite grain boundaries, where the energy required to form a nucleus of a given volume is less than at sites completely within the grains.

INVERSE STEP-QUENCH EXPERIMENTS

After this comprehensive series of two-temperature treatments, a shorter series of similar tests, called ' inverse ' step-quench tests, was carried out in which the second isothermal soaking temperature was higher than the first.

Although the experiments would only be of theoretical interest it was considered that a limited amount of work would be valuable. A few experiments in

Table III

SUMMARY OF RESULTS OF INVERSE STEP-QUENCH EXPERIMENTS

Test Series	Range in which Nucleation was		Soaking Temp., °C.		Total Scheil Fraction After Known Percentage Nucleation at First Temp., %			Class of Result
	Initiated	Completed	First	Second	25% Nucleation	50% Nucleation	75% Nucleation	
46	Ferrite	Ferrite	670	690	69	71	89	A
47	,,	,,	,,	710	83	77	86	A
48	Bainite	Bainite	420	480	59	69	85	A
49	,,	,,	360	,,	75	80	83	A
50	,,	,,	,,	420	100	66	133	...
51	Bainite	Ferrite	480	690	46	59	81	A
52	,,	,,	,,	670	...	68	88	A
53	,,	,,	420	690	112	68	86	...
54	,,	,,	,,	670	73	79	90	A
55	,,	,,	360	690	44	69	...	A
56	,,	,,	,,	670	53	68	86	A
57	Pearlite	Pearlite	600	620	>140	>140	115	C
58	,,	,,	580	,,	>140	>140	115	C
59	,,	,,	,,	600	116	94	>120	C
60	Bainite	Pearlite	480	620	>120	>120	>120	C*
61	,,	,,	,,	600	>130	>130	>120	C*
62	,,	,,	420	620	>130	>130	>120	C*
63	,,	,,	,,	600	>120	>120	>120	C*

* Note that no pearlite was formed as a result of these heat-treatments

each of the temperature ranges were carried out, to investigate the general effect of partial nucleation at the lower temperatures on the higher temperature transformation. Results are summarized in Table III.

Owing to the limited number of experiments, any conclusions drawn from the results are likely to be less certain than those from the corresponding normal step-quench tests. Furthermore, there is likely to be a greater experimental error, mainly because the specimens are cooling during any period when they are suspended freely in air (*i.e.*, during transfer from one furnace to another), and although this is not of great moment when the second furnace is at a lower temperature than the first, it may have a serious effect when transferring specimens to a bath at a higher temperature. The error may be caused either by the longer time required for the specimens to reach the temperature of the second furnace, or by unwanted nucleation occurring during the period of cooling.

Table III shows that all the experiments involving entirely ferrite nucleation (46–56) have class *A* results, with total fractions less than 100%, except for two 'variable' results. The results agree with those obtained from the normal step-quench experiments, but it may be noted that the average value of the total Scheil fraction is lower in the case of the inverse experiments. The two variable results can be accounted for by the explanation given above.

In the case of the experiments in the pearlite range the results are in class *C*, *i.e.*, have total Scheil fractions greater than 100%. This is contrary to expectations, and the high total fractions obtained were probably caused by a temperature drop into the bainite range, between the isothermal treatments.

Experiments 60–63 are, however, different, in that specimens in these tests were 'partially nucleated' in the bainite range (ferrite nuclei) and then transferred to the pearlite range of carbide nucleation. In these circumstances, total fractions greater than 100% may well be in order, but the feature of these tests was that none of the heat-treated specimens showed any trace of pearlitic products formed at 600° or 620° C. All the specimens had partially transformed to bainite, and transformation must have occurred either during the first isothermal treatment, or between the two treatments. Therefore, the actual figures for the total Scheil fraction are meaningless, and the results of these tests ought to be ignored when considering the general effects of the results obtained.

CONTINUOUS-COOLING EXPERIMENTS

Although the Scheil fractional-nucleation hypothesis seems to have limited usefulness in predicting the start of transformation during a two-temperature heat-treatment, it was considered desirable to investigate the application of the hypothesis to conditions of continuous cooling, as these approximate more closely to industrial conditions.

It was found possible to obtain experimentally cooling rates between 3° and 30° C./min., after the standard austenitizing treatment of 835° C. for 30 min. Eight cooling curves, which were fully reproducible, were obtained.

The method suggested by Pumphrey and Jones[8] of predicting the time and temperature at which transformation will start (assuming Scheil's hypothesis to be correct) was followed. The cooling curves are shown in Fig. 2. Curves showing the calculated relationship between temperature and time for the start of transformation are also included.

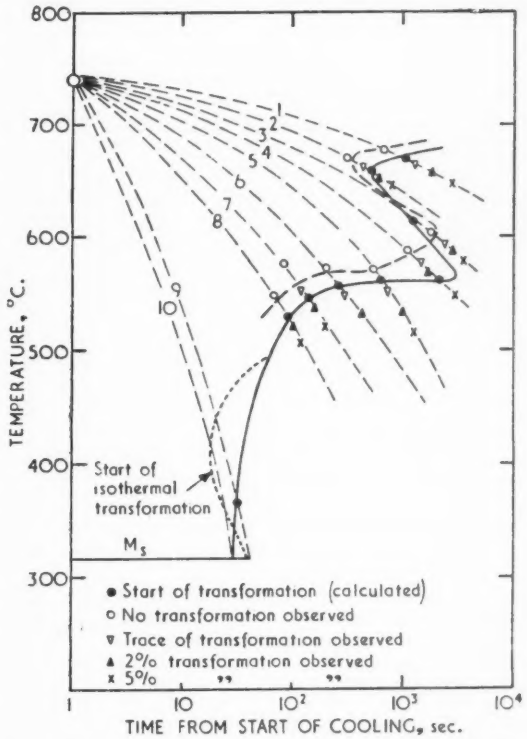

Fig. 2—Continuous cooling curves, showing calculated and observed times for commencement of transformation, and isothermal transformation curve superimposed from Fig. 1

The experiments consisted in cooling a series of specimens, in accordance with each of the cooling curves in turn, and quenching individual specimens at various time intervals after the start of cooling, so as to determine the time and temperature at which breakdown of the austenite commenced.

Curves 9 and 10 in Fig. 2 refer to the critical rate of cooling for this steel. By calculation, cooling in accordance with curve 9 should permit transformation to begin above the M_s temperature, the first product being bainite. Cooling in accordance with curve 10, however, exceeds the critical rate, and direct transformation to martensite would be expected.

Although it was not possible to carry out experiments at cooling rates near the critical rate, it can be seen from comparison of the cooling curves with the isothermal diagram (Fig. 1) that the latter cannot reliably be used to predict the critical cooling rate. Thus, the line representing the commencement of isothermal transformation, when superimposed on cooling curve 10, indicates that partial transformation to bainite would occur in a specimen cooled in accordance with the curve. On the other hand, the

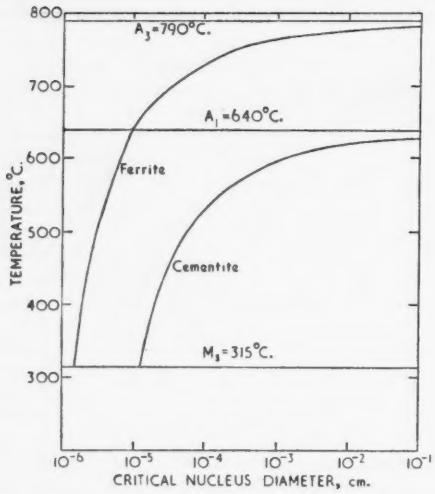

Fig. 3—Variation of critical nucleus size with temperature

start of transformation calculated from Scheil's hypothesis for the same cooling curve indicates that complete hardening would be achieved.

This is a point of some practical importance, since it clearly shows the difficulty of applying the isothermal diagram to anisothermal conditions, and is a worthwhile application of the Scheil hypothesis.

The correlation between the observed and calculated start of transformation on each of the cooling curves 1–8 is reasonably good, particularly in the upper bainite range (curves 5–7). In both the pearlite and bainite ranges (curves 1, 2, and 8), however, the calculated curve indicates that the transformation should begin earlier than, in fact, it did experimentally, and this is generally a margin on the safe side, so that prediction of behaviour may confidently be made on the basis of the calculated data.

This does not apply in the lower portion of the pearlite range (cooling curves 3 and 4), and the margin of error is largest in this range, since the transformation curves and cooling curves have approximately the same slope. The fact that little practical use is made of temperatures in this range makes the discrepancy less serious.

A further disadvantage of this method is that the calculated curve representing the start of transformation is dependent on the shape of the cooling curves. The resulting transformation curves will not vary markedly in shape, but may be moved relative to the temperature and time axes of the graph by using different time/temperature relationships. The amount of movement is, however, likely to be small.

THE INCUBATION PERIOD

Studies of the transformation processes, using the concepts of thermodynamics and statistical mechanics, have been made by Zener[10] and West.[11] Zener gives a method for the calculation of critical nucleus size at any temperature, and the curves shown in Fig. 3 have been obtained by this method.

A summary of the modern views of the decomposition of austenite has been set out by Fisher,[12] who suggests methods of formation of pearlite and bainite, and stresses the importance of the type of nucleus required to form the various products. It is now generally agreed that the primary constituent in the nucleation of pro-eutectoid ferrite or of bainite is an α-iron nucleus, whereas that in the formation of pro-eutectoid cementite or of pearlite is an Fe_3C nucleus.

The theories of the morphology of the transformation products have been well summarized by Mehl.[13]

Earlier, Johnson and Mehl[14] had pointed out that the processes of austenite decomposition normally occur by nucleation and growth, and that the progress of transformation could therefore be determined in terms of the two variables N, the rate of nucleation, and G, the rate of growth. (Note that this does not apply to the martensite transformation, which proceeds by a lattice shearing action).

The rates of nucleation and growth have been related to other known or determinable quantities by various workers, notably Blanter,[15] and Dorn *et al.*[16]

At certain temperatures, in particular those in the upper part of the ferrite range (where the grain size may be measured), and in the upper part of the pearlite range (where the interlamellar spacing may be measured), it is possible to gain some knowledge of the appropriate rates of growth by carrying out such measurements.

This has been done for the production of pro-eutectoid ferrite at 700° and 675° C., the particle diameter being taken as the average dimension of the largest visible grain, on the assumptions that the largest visible grain was that which had been nucleated first, and that it had been cut most favourably through the greatest cross-section by the plane of polish.

The results of these measurements are plotted in Fig. 4. The smallest visible particle size has been taken as 1 mm. dia. at a magnification of 1000, and

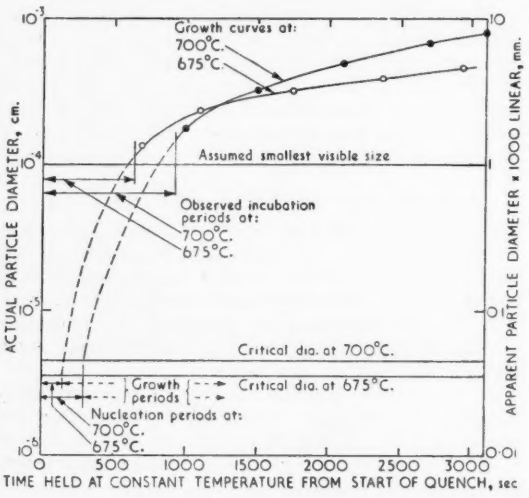

Fig. 4—Suggested mechanism of growth of ferrite from austenite

the critical diameters at the two temperatures concerned have been included.

The comparative slopes of the two curves, at any given time, are an indication of the relative rates of growth of ferrite at the two temperatures, this growth rate being greater at 700° C. than at 675° C., as would be expected.

By extrapolation of the growth curves backwards to the critical size at the appropriate temperature, it is seen that the time interval from the start of the isothermal treatment up to the first visible signs of transformation, known as the ' incubation period,' should be divided into two separate periods: ' period of nucleation,' followed by a ' period of growth,' which will extend, of course, beyond the completion of the incubation period. Since the grain studied was assumed to be that which had begun to transform first, other grains will either have a longer nucleation period, followed by a similar period of growth, or will have the same nucleation period, preceded by a period of no action. It cannot be said conclusively which is the actual state of affairs, but it seems much more likely that the nucleation period will vary from grain to grain.

Thus the process of nucleation (*i.e.*, the chance formation of areas within the austenite, of ferrite or cementite, followed by the appropriate atomic rearrangement to the new lattice) takes an appreciable time irrespective of the rate of nucleation. (The rate of nucleation only defines the number of nuclei formed in relation to time). The time, however, may be a relatively small proportion of the observed incubation period. As during this latter period the old lattice rearranges itself to replace the new lattice, the new lattice so formed becomes continuous with the previously formed lattice in the original nucleus.

Thus, the time at which transformation will begin, as shown by visual evidence or other standard methods, will depend on any local variations in original austenite composition. Since no normal austenitizing treatment will ensure complete absence of composition gradients within the austenite, a further unknown variable is introduced, and it is believed that this may be the explanation for some of the anomalous results reported earlier.

CONCLUSIONS

(1) The ' fractional-nucleation ' theory of Scheil has been used for the prediction of the start of transformation during step-quenching. In general, the correlation was poor, transformation beginning earlier than predicted when nucleation was wholly either in the α-iron (ferrite or bainite) or in the Fe_3C (pearlite) range. In addition, the transformation occurred later than predicted when nucleation began in one range and was completed in the other. These discrepancies were explained by the disproportionate effect of early nucleation on later nucleation at a different temperature, and the variation with temperature of the critical nucleus size.

(2) By contrast, good correlation was found between the predicted transformation behaviour during continuous cooling and the observed behaviour. It is suggested in this connection that the disproportionate nucleation effect observed in the step-quench experiments has no chance to operate, since the critical nucleus size is continually diminishing as the temperature falls. The absence of an arrest in going from the range of one nucleating agent to that of the other, as was noted in the step-quench experiments, has not, however, been fully explained. The correlation between the predicted and observed transformation behaviour during continuous cooling is sufficiently good to suggest that a similar correlation may be shown by other steels; in which case, the theory could be used for predicting the degree of hardening resulting from a given heat-treatment, and particularly, for predicting whether complete hardening was to be expected.

(3) Suggested mechanisms for the decomposition process of austenite into its various products have been discussed, and a new interpretation of the incubation period has been put forward. This is based on the established concepts of nucleation and growth, and shows the possible effects of austenite heterogeneity on subsequent transformation.

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The Formation and Decomposition of Fayalite ($2\,FeO.SiO_2$)

By B. G. Baldwin, B.Sc., Ph.D., A.R.I.C., D.I.C,

SYNOPSIS

The effect of particle size, time of heating, and temperature on the formation of fayalite from mixtures of ferrous oxide and silica have been investigated. The influence of alumina, magnesia, lime, and dolomite on fayalite formation has also been studied. 938

It is well known that ferrous oxide combines with silica at elevated temperatures to form fayalite. Little information is available on the kinetics of this reaction in the solid state or on the precise effect of the presence of other oxides on the reaction.

This reaction is of interest in the study of the blast-furnace process in that fayalite is more difficult to reduce to iron than free ferrous oxide. Furthermore, fayalite is often a constituent of commercial sinters and causes an increase in strength of the material at the expense of its reducibility.

A number of experiments have been carried out to determine the effect of particle size and temperature on the formation of fayalite from ferrous oxide and silica.

Experiments have been conducted in the past to diminish the amount of fayalite in sinters by incorporating other substances into the sinter mix (*e.g.*, lime), and so the effect of lime, magnesia, alumina, and dolomite on the formation of fayalite from ferrous oxide and silica at various temperatures has also been studied.

APPARATUS

The apparatus is shown diagrammatically in Fig. 1. It consisted of a Kanthal-wound electric furnace *A*, which contained a mullite tube *B*, 80 cm. long × 3 cm. inside dia. At the upper end was a water-cooled brass adapter *C*, which was waxed on to the mullite tube and to a *B*29 ground Pyrex joint *D*. The wires of a Pt/Pt–13% Rh thermocouple *E* were brought out through a soft-glass *B*19 ground joint *F*. The sample was held in an iron crucible *G*, 2½ cm. × 1 cm., connected by Nichrome wire to a soft-iron counterweight *H*. By moving the magnet *J* the crucible could be moved rapidly and smoothly up and down the furnace. A glass guide *N* was placed inside the ground Pyrex joint *D* to keep the Nichrome wire coaxial with the mullite tube.

A double-walled brass cooling chamber *K* was waxed on to the lower end of the mullite tube. On to this chamber was waxed a *B*29 Pyrex joint *L* fitted with a stopper *M*. A flow of nitrogen was passed through the apparatus during a run and provision was made for evacuation before beginning.

EXPERIMENTAL TECHNIQUE

The glass stopper *M* was removed and the Nichrome wire was lowered (by raising the counterweight *H*) so that it protruded from the lower end of the furnace. An iron crucible, containing the sample to be heated, was hooked on to the Nichrome wire, the crucible was raised to the centre of the cooling chamber *K*, and the glass stopper *M* was replaced. The temperature of the furnace was adjusted to that required for the experiment. The reaction tube was evacuated and filled twice with pure nitrogen, re-evacuated, and the crucible and contents were rapidly raised to the centre of the furnace. This vacuum treatment was carried out to minimize oxidation of the ferrous oxide. After 1 min. nitrogen was admitted to the apparatus and a slow stream (0·5 c.c./sec.) was maintained during the remainder of the heating period. At the completion of this period the crucible was quickly lowered to the centre of the cooling chamber and a rapid flow of nitrogen (15 c.c./sec.) was passed through the apparatus. After 10 min. the crucible was cool enough to be removed.

In the cases where the sample after heating was in the powdery condition, no difficulty was experienced in removing it from the crucible. Samples which had been melted were removed from the crucible by squeezing it in a steel vice.

The sample was analysed by an X-ray powder diffraction method using CoKα radiation and a 9-cm. camera. To portions of the basic ferrous-oxide–silica mixture used in this series of experiments was added 5%, 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 95% of pure fayalite, and a set of standard X-ray powder-diffraction photographs was obtained from these mixtures. As the percentage of fayalite increased, the intensity of the lines on the photograph due to fayalite becomes greater at the expense of those due to ferrous oxide and silica. By visual comparison of the standard photographs with that of an unknown mixture it was possible to

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estimate the percentage of fayalite with an accuracy of ±5%. Microscopic examinations were also carried out on thin sections of the samples when suitable.

PREPARATION OF MATERIAL

Ferrous oxide was prepared from pure carbonyl-iron powder. A portion of the iron was heated in oxygen at 1100° C. for 24 hr., cooled, and crushed. This procedure was repeated until the product was shown by analysis to be pure ferric oxide. (It was found that crushing could be carried out more easily when the material had been heated in oxygen than in air.) The ferric oxide was then ground to −200 B.S. mesh, mixed with a stoichiometric amount of carbonyl iron, heated for 6 hr. at 900° C. in an inert atmosphere, and then cooled rapidly. The product was analysed to ensure that all the iron and ferric oxide had reacted and that no decomposition of the ferrous oxide had occurred during cooling.

A sample of pure quartz was used as a source of silica. Lime was obtained by ignition of Analar-grade calcium carbonate, and alumina and magnesia by ignition of the Analar grades. The sample of kaolinite* was of a high degree of purity. Ignited dolomite was obtained from material which had the following analysis : CaO, 31·25% ; MgO, 20·80% ; S, 0·014% ; Al_2O_3, 0·05% ; Fe_2O_3, 0·68% ; insol., 0·45% ; ignition loss, 46·52%.

The mixtures of ferrous oxide and silica used in the subsequent work were in the correct proportion to give fayalite.

RESULTS

Effect of Particle Size

A number of experiments were carried out by heating mixtures of ferrous oxide and silica of known particle size. The particle sizes chosen were 100–150, 150–200, 200–300, and −300 B.S. mesh (these correspond to 0·152–0·105, 0·105–0·076, 0·076–0·053, and <0·053 mm.). Little formation of fayalite occurred in the solid state when the particles comprising the mixture were larger than 200 mesh, as shown below (the time of heating was 1 hr. and the temperature was 1100° C. in each case) :

Mesh Size (B.S.)	100–150	150–200	200–300	−300
Fayalite, %	3	3	45	50

When all the mixtures were heated to 1200° C. fusion occurred and the product consisted of nearly 100% fayalite in each case.

The remaining work in this investigation was carried out with mixtures of 200–300 B.S. mesh powders.

Effect of Time

The influence of the time of heating of the mixture was very small. The amount of fayalite formed after heating for 24 hr. was found to be almost the same as that after heating for 15 min. The amount of fayalite formed after 5 min. was often found to be slightly less than for times greater than this, as shown below :

Temperature 1100° C.						
Time, min.	5	15	30	60	120	24hr.
Fayalite, %	35	40	40	40	40	45

*Supplied by the Macaulay Institute for Soil Research, Aberdeen.

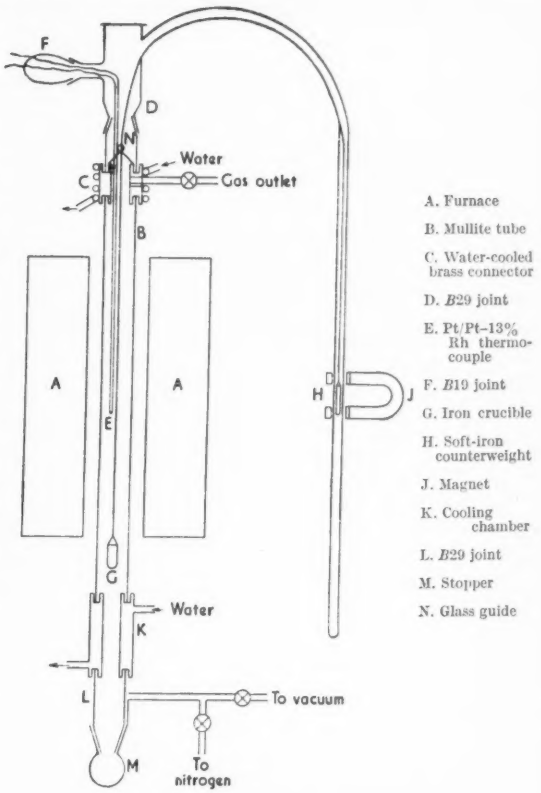

Fig. 1—Diagram of apparatus

The reason for this difference is considered to be the rate of heating of the cold powder to the temperature of the experiment. It was later shown that almost 5 min. was required to raise the powder to the furnace temperature.

The effect of particle size and the minor influence of variation of time of heating on the rate of formation of fayalite suggest that there is little mobility of the molecules below the temperature of fusion. Only where an intimate mixture of ferrous oxide and silica occurs in an iron ore will fayalite formation be extensive below the melting point. In ores of the Mesabi taconite type, where a very intimate mixture of iron oxide and silica occurs, ready formation of fayalite is to be expected during reduction at high temperatures. Where the silica is in the form of bands through a relatively pure iron oxide matrix, or where large crystals of quartz are found in the ore, fayalite formation below the temperature of fusion will be restricted to the iron-oxide/silica interface.

Effect of Temperature

No fayalite was detected after prolonged heating of the basic ferrous-oxide–silica mixture at 700° C., but at temperatures of 800° C. and above interaction occurred. Owing to the minor influence of the time of heating, as shown by the results quoted, the time of heating for all the samples was standardized at

15 min. ; this avoided unnecessarily prolonged heating periods.

The results obtained were :

Temp., ° C.	800	900	1000	1050	1100	1200
Fayalite, %	5	10	25	35	40	95(*F*)*

In all cases where fusion occurred, complete, or almost complete, formation of fayalite was found.

It will be seen that with increase in temperature the rate of interaction of silica and ferrous oxide increases. The method of analysis used (an X-ray powder diffraction technique) is not accurate enough for a reliable estimate of the apparent energy of activation of the process to be made from these results, but it is of the order of 18 k.cal./g.mol.

EFFECT OF ADDITIONS OF OTHER SUBSTANCES ON THE REACTION BETWEEN FERROUS OXIDE AND SILICA

Effect of Addition of 10% of Alumina

A series of experiments were carried out using the basic 200–300 mesh mixture, to which was added 10% of alumina of the same size grading. The effect of this addition on the formation of fayalite was studied at various temperatures. As in the previous series of experiments, the time of heating was 15 min. in all cases.

Analysis of the X-ray diffraction photographs was complicated by the presence of hercynite (ferrous aluminate, $FeO.Al_2O_3$), which was formed by combination of the alumina with ferrous oxide. The ferrous oxide content of the product was diminished by this reaction, so that in comparing the X-ray diffraction photographs the progressive disappearance of the silica lines and the appearance of the fayalite lines were used to estimate the percentage of fayalite formed. The rate of formation of fayalite was enhanced by the presence of 10% alumina :

Temp., ° C.	900	1000	1050	1100	1200
Fayalite (basic mix), %	10	25	35	40	95(*F*)
Fayalite (mix + 10% Al_2O_3), %	5	30	50	85(*F*)	85(*F*)

Free alumina was found in all the end products up to 1050° C. At 1100° and 1200° C. all the alumina was combined in the form of hercynite. The presence of alumina increased the rate of formation of fayalite at 1000° and 1050° C. without apparently taking part in any reaction.

The formation of hercynite at the expense of fayalite in heated ferrous-oxide–silica–alumina mixtures is in agreement with the standard free energies of formation of these compounds. For example, the free-energy change $\Delta G°$ at 1100° C. for the formation of hercynite is −10 k. cal., and that for fayalite is −4·9 k. cal.[1]

However, the fact that the free-energy change for one reaction is greater than another does not necessarily imply that that reaction will occur. The free-energy changes for the formation of various aluminium silicates are considerably greater than those for the formation of hercynite and fayalite (they are of the order of −40 k. cal.), and this suggests that these compounds should have been formed preferentially. Their very high melting points appear to preclude their formation at a finite rate at the temperatures used, and in fact none of these compounds was identified.

Since the alumina does combine with ferrous oxide above 1050° C. to give hercynite, the overall amount of fayalite produced from a fused mixture of ferrous oxide and silica is decreased by the addition of alumina. However, the presence of alumina is shown to increase the rate of formation of fayalite at temperatures below the fusion point. The presence of alumina in iron ores or commercial sinters is not desirable if a reducible material is required, since both fayalite and hercynite are reduced with difficulty.[2]

Effect of Addition of 10% of Magnesia

A series of experiments, similar to the preceding one, were carried out with additions of 10% of magnesia. The time of heating in all cases was 15 min. Very slight line shift was observed in the fayalite pattern obtained from the sample heated to 1200° C. and an excess of ferrous oxide was noted. Optical examination of the product revealed the presence of a forsterite–fayalite solid solution having an approximate composition of 80% of fayalite and 20% of forsterite. No formation of a solid solution was observed below 1200° C., so that the determination of the fayalite content in samples heated below this temperature was unaffected by addition of magnesia. This sample, heated to 1200° C., was found to be a strong sinter and not the usual melt, and only a trace of free magnesia was present. Free magnesia was found in all the other samples. The results obtained were :

Temp., ° C.	900	1000	1050	1100	1200
Fayalite (basic mix), %	10	25	35	40	95(*F*)
Fayalite (mix + 10% MgO), %	5	15	20	30	80

The results show that the presence of 10% of magnesia diminished the rate of formation of fayalite. Since the magnesia was unchanged (except at 1200° C.) at the completion of the experiment, it presumably acted as an inert diluent and kept the ferrous oxide and silica particles apart.

Effect of Lime Addition

It has been stated that fayalite formation in sinters is prevented by the presence of lime,[3] so that the system was investigated more fully than the two preceding ones, with samples containing a range of lime/silica ratios (g. mol. of lime/g. mol. of silica). As in the previous experiments, mixtures of ferrous oxide and silica to which various known amounts of of lime had been added were heated for 15 min. at various temperatures between 700° and 1300° C. Under none of these conditions was any detectable amount of fayalite formed.

Lime/Silica Ratio = 0·4 (10% *of Lime*)—Below 1100° C., lime, silica, and ferrous oxide remained unchanged. Above this temperature the mixture fused and the end product was composed of iron monticellite ($CaO.FeO.SiO_2$) and free ferrous oxide.

*F signifies in this and later tables that the mixture had fused.

Lime/Silica Ratio = 1·0—The mixture behaved in an identical manner to that described above.

Lime/Silica Ratio = 2·0—At temperatures below 1100° C. an unchanged powdery mixture of lime, silica, and ferrous oxide was found. Above 1100° C. the mixture fused, but on removal from the furnace the crucible contained powdery γ dicalcium silicate (produced from the β form) and free ferrous oxide.

Lime/Silica Ratio = 4·0—At temperatures below 1000° C. an unchanged mixture of lime, silica, and ferrous oxide was found. At temperatures between 1000° and 1200°C., β dicalcium silicate, free ferrous oxide, and free lime were formed. The temperature of fusion was about 1100° C. and it is interesting to note that this is the first time where formation of a calcium silicate was found to have occurred in the solid state. Also, dusting due to the β → γ silicate transformation did not occur ; β dicalcium silicate was found in the end product despite the fact that the method of cooling was identical with that for the experiments described in the preceding section. At 1300° C. tricalcium silicate was formed, together with unchanged ferrous oxide. The suppression of the formation of fayalite in ferrous-oxide–silica mixtures by the addition of lime, as in the case of alumina, is in agreement with the known thermodynamic data for these reactions, the standard free energies of formation of di- and tricalcium silicates from lime and silica being −30 k. cal. in each case, and that for fayalite being only −4·9 k. cal.

With small amounts of lime, part of the ferrous oxide is held in the form of iron monticellite ; with larger amounts of lime the ferrous oxide is eliminated completely from all silicate complexes. No mixtures of silicates were encountered and no monocalcium silicate was found.

The results of the present investigation satisfactorily explain the observations of Takahashi,[4] who measured the reducibility of partially reduced briquettes of mixtures of ferric oxide, silica, and lime. Cases where he observed low reducibilities were found in this investigation to coincide with the optimum conditions for the formation of fayalite (*i.e.*, no lime present). The addition of lime was found to improve the reducibility only when a certain minimum amount was added. This amount is shown in the present investigation to be that required to remove all the ferrous oxide from a silicate complex (*i.e.*, lime/silica ratio $\geqslant 2$).

Addition of 10% of Calcined Dolomite—For practical reasons the use of dolomite may be preferable to that of lime for the suppression of fayalite formation in commercial sinter-making, since it is a ready source of lime and magnesia. Hence experiments were carried out with mixtures containing 10% of calcined dolomite. No fayalite was formed at any of the temperatures used (700–1200° C.). In samples heated to temperatures above 1100° C. the X-ray diffraction patterns indicated that the free silica, magnesia, and lime concentrations diminished, as shown by a reduction in their intensity relative to the unchanged ferrous oxide. A new crystalline phase was formed which has not been identified but may be presumed to be a complex calcium magnesium silicate, possibly merwinite.

Effect of Lime on Fayalite at High Temperatures

Mixtures containing 200–300 mesh fayalite with lime (lime/silica ratio = 0·4) were heated at temperatures between 700° and 1300° C. The X-ray diffraction photographs showed that the fayalite was decomposed by lime at temperatures of 1000° C. and above. The change in colour of the samples (pale yellow → brown) suggested that decomposition had in fact begun at 800° C. The products obtained by heating fayalite at 1150° and 1300° C. with an amount of lime equivalent to a lime/silica ratio of 0·4, 1, 2, and 4 were identical with those obtained from the basic ferrous-oxide–silica mixtures with the equivalent amount of lime added, described in an earlier section.

It is thus evident that if fayalite formed in the blast-furnace or during sintering comes into contact with lime-bearing materials, rapid decomposition of the fayalite will occur. This is most likely to take place in the blast-furnace at temperatures above 1100° C. Free lime which would otherwise be available for desulphurization in the bosh zone may be removed by the decomposition of fayalite into calcium silicate and ferrous oxide.

Formation of Fayalite from Kaolinite and Ferrous Oxide

Impurities in iron ores are frequently composed of clay-type minerals. One of the most common minerals in these clays is kaolinite ($Al_2O_3.2SiO_2.2H_2O$) and formation of fayalite may occur during reduction of the ore. A number of experiments were therefore carried out to determine the rate of formation of fayalite from a stoichiometric mixture of ferrous oxide and silica in the form of kaolinite, which had been calcined to remove the combined water. The results were :

Temp., ° C.	900	1000	1050	1100	1200
Fayalite, %	10	20	70	60(*F*)	60(*F*)

As in the experiments reported previously, with a 10% alumina addition hercynite was formed above 1050° C. The lower amount of fayalite formed at 1100° and 1200° C. than at 1050° C. is due to the combination of part of the ferrous oxide with alumina, thus reducing the amount available for combination with silica to form fayalite. All the ferrous oxide at 1100° and 1200° C. was combined either with alumina or silica.

When an intimate mixture of kaolinite and iron oxide is present in an ore, ready formation of fayalite should occur during reduction.

A further series of experiments were carried out with additions of lime to the kaolinite–ferrous-oxide mixture to give a lime/silica ratio of 1. As in the case of lime additions to the basic ferrous-oxide–silica mixture, no fayalite was formed when the mixture was heated at 700–1300° C.

CONCLUSIONS

(1) Formation of fayalite can occur during the reduction of iron ores, or during sintering above 800° C. when ferrous oxide and silica are present and in the absence of lime.

(2) Formation of fayalite will only occur readily at temperatures below the fusion point where an intimate mixture of iron oxide and silica is present.

(3) Formation of fayalite will occur more readily when alumina is present; formation of hercynite, which, like fayalite, is more difficult to reduce than the free oxide, will also take place at temperatures above 1050° C.

(4) Formation of fayalite will occur less readily in the presence of magnesia, since this acts as an inert diluent.

(5) When lime is present in the mixture, formation of fayalite is completely suppressed. With small amounts of lime (lime/silica ratio $\leqslant 1$) part of the ferrous oxide is held in the form of iron monticellite. With large amounts of lime (lime/silica ratio $\geqslant 2$) the ferrous oxide is completely eliminated from all silicate complexes.

(6) Lime decomposes fayalite at temperatures above 800° C.

(7) Formation of fayalite is suppressed by the presence of dolomite.

(8) Ferrous oxide will combine with the clay mineral kaolinite to give fayalite. The formation of fayalite in this way can be suppressed by addition of lime.

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The Nature of Ironstone Sinter

By

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SYNOPSIS

This paper gives the first results of work on the constitution of sinters produced normally on the Appleby-Frodingham Dwight-Lloyd plant, supplemented with experimental sinters made on a laboratory unit. Ironstone sinter, as made at Appleby-Frodingham, consists of iron oxide crystals, principally magnetite, set in a matrix of crystalline silicates and glass. This matrix closely resembles the blast-furnace slag formed in all-sinter practice, but has not attained such equilibrium. 944

Improved furnace output and reduced coke consumption at Appleby-Frodingham[1] have amply demonstrated the benefit of sintering the fines arising from the crushing and screening of Frodingham and Northants ironstones. Normally, sinter has comprised some 33% of the blast-furnace burden, the balance being lump ore. However, as a result of post-war trials, one 25-ft. furnace has been operated for a prolonged period on the basis of 100% sinter burden. The spectacular gain in output, coupled with the saving in metallurgical coke thus achieved, has led to the extension of this all-sinter practice to a second similar furnace.

The overall reduction in fuel consumption in all-sinter practice is small, the saving in metallurgical coke being largely offset by the coke-breeze requirement for sintering. A considerable part of the metallurgical work of the blast-furnace is now accomplished on the sinter strand with a cheaper fuel, for ironstone sinter is essentially a pre-formed solidified slag containing finely disseminated crystals of magnetite and, to a lesser extent, hematite. The chemical composition of this 'sinter-slag', formed by the inter-reaction of the mineral constituents of the raw ores during sintering, is only slightly modified in the blast-furnace by the incorporation of coke ash and of fragments of ore too coarse to be assimilated on the sinter strand.

The characteristics of sinter are thus of paramount importance in this new development, for in large measure they must determine the behaviour of the blast-furnace burden during smelting. Published work on the nature of ironstone sinter, and the relation of physical properties of ironstone sinter to its

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Table I

CHARACTERISTICS OF ORE AND FEED[5]

Typical Analyses of Ore and Feed, %

Composition	Frodingham Ore			Northants Ore			Feed*		
	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.
Moisture	8·5	12·6	1·0	8·5	9·96	7·05	11·2	12·64	7·76
Fe	24·8	28·8	18·6	40·2	45·5	34·0	31·6	33·0	28·8
CaO	16·2	28·2	8·8	2·4	4·9	0·7	12·2	13·8	10·9
MgO	—	1·81	tr.	1·0	2·46	0·14	1·7	2·6	1·23
Al_2O_3	5·2	7·8	1·8	7·8	10·6	4·4	8·4	9·9	4·7
SiO_2	9·9	12·6	3·6	15·7	18·2	11·2	14·4	17·4	13·0
CO_2	17·0	35·4	10·7	2·3	4·8	1·0	12·8	16·4	10·5
P_2O_5	1·3	2·54	0·69	1·9	3·04	1·44	1·2	1·53	0·95
Free carbon	—	—	—	—	—	—	4·7	6·9	2·8

Grading Analyses, wt.-%

Size Grading, in.	Frodingham Ore			Northants Ore			Feed		
	Aver.	Max.	Min.	Aver.	Max.	Min.	Aver.	Max.	Min.
+ 1	0·6	2·9	0	0	0	0	0·4	1·2	0
+ ¾	2·6	9·2	0	0	0·2	0	2·2	4·7	0·9
+ ½	9·9	19·4	1·1	0·5	1·8	0	10·4	16·9	2·8
+ ¼	27·1	39·8	12·2	18·7	34·4	9·3	38·2	46·5	32·4
+ ⅛	43·2	55·0	27·2	46·1	58·9	33·7	58·2	62·7	52·8
+ 1/16	56·8	66·8	42·7	61·9	71·5	43·5	70·4	75·1	64·9
+ 1/32	72·3	81·9	62·7	72·3	80·2	63·6	81·8	86·0	76·6
− 1/32	27·7	37·3	18·9	27·7	36·4	19·2	18·2	23·4	14·0

*Including circulating load, flue dust, and coke. All data were taken on the same shift, so that an exact comparison with ores was not possible owing to the lag effect of the circulating load.

constitution, is so scant that research on this aspect has therefore been initiated at the Research and Development Department of The United Steel Companies, Ltd., in Rotherham. This paper gives the first results of work on the constitution of sinters produced normally on the Appleby-Frodingham Dwight-Lloyd plant, supplemented by experimental sinters made on the Research and Development Department laboratory unit.[2] In subsequent papers it is hoped to relate the constitution to physical properties, notably viscosity.

THE FEED TO THE SINTER PLANT

Present Appleby-Frodingham practice is based on roughly two parts of Frodingham ore to one of Northants ore, with a circulating load of 40–45% of the total mix. Essentially, the Frodingham ores[3] consist of oöliths of chamosite, in a matrix composed of siderite, or siderite and fine chamosite flakes, or clear crystalline calcite. In the Northants ores[4] chamosite oöliths, and sometimes angular quartz grains, are surrounded by a matrix of siderite, frequently containing some chamosite and calcite. Upon weathering, the siderite oxidizes to limonite, and chamosite in the oöliths and matrix changes to limonite and an iron-free clay. Pyrite (FeS_2) and a small amount of gypsum ($CaSO_4.2H_2O$) account for the contribution of the ore to the sulphur in the feed, and minute amounts of collophane ($3Ca_3(PO_4)_2.nCa(CO_3, F_2, O).xH_2O$) add phosphorus.

The characteristics of the ore and feed are given in Table I.

The sizing of the feed is of special significance since most fragments larger than ¼ in. dia. do not sinter completely and generally differ in composition from the smaller particles. For example, the ironstone fines are all nominally −¼ in. in size, but grading analyses of the Frodingham fines during the '39 Steps' trials[5] showed that actually 27% was +¼ in. This coarser fraction usually has a CaO/SiO_2 ratio between 2·0 and 2·5, being largely composed of shell fragments and calcite-rich aggregates, whilst the −¼ in. fraction has a mean ratio between 1·0 and 1·5. The Northants fines have 19% oversize, which is slightly higher in silica than the rest, although the difference in composition of the two fractions is small compared with that of the Frodingham ore. The CaO/SiO_2 ratio for +¼ in. Northants fines lies between 0·1 and 0·15, whilst that for the −¼-in. material lies between 0·15 and 0·20.

With the addition of water during mixing, the fine clay particles in the ore adhere to one another and to the larger fragments. As the mix feeds on to the strand through a swinging spout, a natural sorting occurs such that the coarser material tends to form a layer on the grate bars overlaid by the finer material. Although this coarser material contains a greater proportion of the natural +¼-in. fraction of the ore fines and circulating load, chemical analyses have not revealed any consistent variation in the relative proportions of lime and silica corresponding to a local

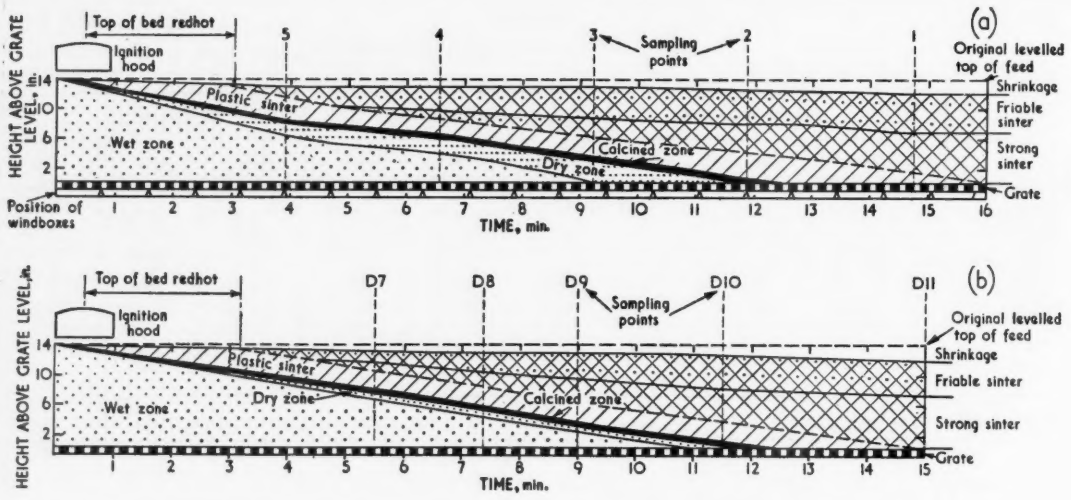

Fig. 1—Structure of sinter beds (diagrammatic) : (*a*) Zone structure developed on Dwight-Lloyd strand; (*b*) laboratory-unit results arranged to simulate performance on Dwight-Lloyd strand

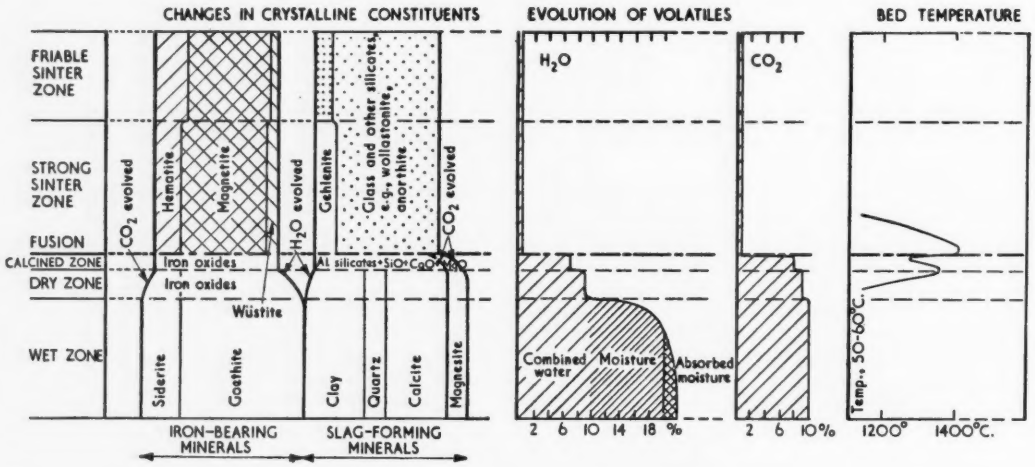

Fig. 2—Changes in constitution during sintering. (Minerals in relative proportions as determined from petrological, X-ray, and chemical analysis. Some clay and goethite may be combined as chamosite. Magnetite is represented separately although it is present partly in solid solution in siderite and partly as dolomite)

Table II

CHEMICAL COMPOSITION OF ZONES FROM WORKS STRAND

Average analyses (%)—dry basis

Zone	Fe	Fe_2O_3	FeO	CaO	MgO	Al_2O_3	SiO_2	CO_2	Combined H_2O	C	S
Friable sinter	38·3	32·5	20·0	15·7	1·9	8·7	17·9	0·44	0·08	0·12	0·171
Strong sinter	38·6	32·5	20·4	16·0	1·9	8·8	17·2	0·40	0·03	0·06	0·189
Calcined zone	31·9	35·4	9·1	15·1	1·6	7·5	14·1	7·1	1·99	4·14	0·211
Dry zone	30·8	33·8	9·2	10·7	1·7	7·1	15·5	8·1	4·00	5·65	0·227
Wet zone	31·8	34·5	9·3	12·1	1·6	7·6	14·8	8·8	4·35	5·65	0·337

concentration of lime at the bottom of the bed. There is, however, a greater concentration of the coke (which is all $-\frac{1}{8}$ in.) in the upper layers of the bed.

CHANGES DURING SINTERING

As the levelled sinter bed is carried forward on the Dwight-Lloyd strand, it passes first under the gas hood where the top layers are ignited, and then into the open where cool air is drawn down through the bed ; combustion proceeds almost until discharge from the strand. Dissection of the bed at various stages demonstrates that combustion is limited to an extremely thin layer—the flame front resting on unburnt feed and overlaid by sinter.

Vertical sections through the half-burnt sinter bed, obtained in the manner described in the Appendix, reveal a regular structure, similar in both plant and laboratory trials, which is shown in Fig. 1. On the basis of colour and physical nature, the unburnt feed in the lower part of the bed is divisible into three zones and the sinter in the upper part into two; this is illustrated in Fig. 3, a photograph of a resin-set vertical section through the bed.

The five zones distinguishable are : (1) at the bottom, the wet zone, comprising wet feed of natural colour, additionally moistened by condensation from the waste gases passing down from the top of the bed ; (2) the dry zone, yellow-brown in colour, like the limonite ores dried by the hot combustion gases ; (3) the thin calcined zone, red-brown in colour, very incoherent and adhering to (4) the strong sinter, a massive, strong, porous sinter ; this is succeeded by (5) the friable sinter zone.

The thicknesses of the calcined and dry zones remain remarkably constant for the particular plant until they disappear at the end of the process, whilst the depths of the sinter and wet zones depend upon the length of time for which sintering has been in progress. On the laboratory unit, the calcined zone is $\frac{1}{2}$ in. thick and the dry zone generally 1 in. On the Appleby-Frodingham strand, the calcined zone is approximately the same but the dry zone is thicker—$2\frac{1}{2}$–4 in.—possibly owing to drying while sampling. The maximum depth of friable sinter developed at the discharge is 5 in. in both cases.

Representative samples of the individual zones collected at the Appleby-Frodingham strand were analysed chemically, with results as shown in Table II and Fig. 2.

DETAILS OF ZONES

The Wet Zone

All components of the feed—the iron ores, coke, and return sinter—are readily distinguishable, showing no physical alteration in the wet zone either with the naked eye or under the microscope. This zone is often noticeably wetter than the feed, as a result of the condensation of water given off in the drying and combustion of the overlying feed. The effect is to maintain the temperature at a value normally around 50–60° C., a feature noted in all the tests and remarked upon also by Hessle[6] when describing the zoning of the sinter bed in rich-ore practice at Hofors, Sweden. The temperature rises to 100° C. at the top of this zone where it merges into the overlying dry zone.

Determinations of moisture content of samples from different levels in the wet zone showed a range from nil at the dry-zone contact to values higher than that of the original feed, even at 2 in. below the contact. Thus, the following data were obtained from a feed initially containing 13·8% H_2O :

Depth of Wet-Zone Sample, in.	H_2O, %
2	14·9
4	15·8
6	16·1
8	16·1
10	16·5

The Dry Zone

There is little difference in the mineralogical constitution of the dry and wet zones. However, there is a decrease in combined water, resulting from dehydration of chamosite, limonite, and clay, and a slight fall in the CO_2 content. It is not certain what significance is attached to this CO_2 decrease, but it may be due to the beginning of decomposition of collophane or of siderite. These slight chemical changes are shown graphically, together with X-ray and petrological observations on the mineral changes between the zones, in Fig. 2. (It may be more correct in this instance to represent the chemical changes by smooth curves rather than by steps between the zones.) No siderite remains within the overlying calcined zone, and the bulk of the calcite is unaltered. Thus, the decrease in CO_2 content between the dry and calcined zones is attributed to the dissociation of siderite.

On the laboratory unit, the temperature of the dry zone, as indicated by bare Pt/Pt–Rh thermocouples, ranged from 100° C. at the bottom to as much as 1350° C. at the top.

The Calcined Zone

The calcined zone marks the upward transition from unburnt feed to sinter ; ignition of the coke occurs with fusion and consequent sinter reactions in an extremely thin combustion layer at the top of this zone. The oölitic texture is maintained in the larger fragments of ore, although chemical reactions have caused shrinkage of the oöliths with cracking, as shown in Fig. 6. Pieces of coke, return sinter, and calcite are identifiable among a confusion of reaction products resulting from the dissociation of the clay minerals and siderite and partial decomposition of goethite ($Fe_2O_3.H_2O$). Corresponding with the disappearance of chamosite and reduction in the quantity of goethite, there is an increase in the iron oxides, Fe_2O_3 and Fe_3O_4.

Calcite is dissociated at the very top of the zone when coke ignition occurs, and there is a sudden and marked decrease in CO_2 content so that very little remains in the overlying sinter. This endothermic reaction, $CaCO_3 \rightarrow CaO + CO_2$, is believed to be the chief cause of the drop in temperature, followed by a further rise that was noted on passing from the calcined zone to the strong sinter zone when Frodingham ores were used in the mix.

The Sinter Zones

Immediately after sectioning the bed, a layer of glowing plastic sinter is exposed just above the combustion layer, overlaid by black sinter. On cooling,

the sinter can be classified as ' strong ' or ' friable,' according to the relative ease with which it disintegrates when struck with a hammer. The friable sinter develops at the top of the bed, ultimately attaining a depth of about 5 in. at the discharge end of the strand. Its development is presumably due to the entry of cold air which causes rapid chilling, so producing brittle sinter. Further down, where the sinter is cooled more slowly by the passage of air already preheated by the overlying materials, it is annealed and assumes a tougher nature. When sintering was stopped at a depth of 2 or 3 in. on the strand by covering part of the bed with steel sheets, the sinter thereunder cooled slowly and was much stronger than the top of the adjacent uncovered sinter. Furthermore, on the laboratory unit, if the air entering the bed is preheated sufficiently, the whole sinter bed becomes uniformly strong. This principle might be applied to sinter-plant design in order to increase the yield of strong sinter.

The strong and friable sinters are similar in constitution and microstructure. Both consist of granular crystals of iron oxide, principally magnetite, set in a matrix of crystalline silicates and glass (*see* Fig. 4). Fragments of partly sintered ore are often enclosed, as in Fig. 7. Generally, the proportion of glass to silicates is higher in the friable sinter than in the strong sinter.

CONSTITUTION OF SINTER

The Iron Oxides

Of the free iron oxides, hematite (Fe_2O_3) comprises 15–30% of the friable sinter and 5–30% of the strong sinter, the balance being almost entirely magnetite (Fe_3O_4). Small amounts of wüstite (FeO) are visible as dendrites and laths in the micro-radiographs and polished sections (Fig. 5).

The ' Fe_3O_4 ' phase is present in two spinel forms, one having a lattice parameter near to Fe_3O_4 and one slightly lower. This feature was rather more marked in the laboratory sinters than in those from the works plant. Thus, X-ray examination of 27 works plant samples, both strong and friable sinters, showed that in 12 the lattice parameter of the ' Fe_3O_4 ' constituent was somewhat lower than the value 8·375 kX. for the pure oxide. In three cases, measured values were 8·342, 8·338, and 8·329 kX., respectively. This could be due to :

(i) Some Al_2O_3 or other oxides in solid solution (*e.g.*, either as γ-Al_2O_3 or as $FeAl_2O_4$)

(ii) An unbalanced spinel which may be regarded as representing a state of oxidation somewhere between Fe_3O_4 and γ-Fe_2O_3 (8·315 kX.).

The second of these alternatives could otherwise be considered as a ' solid solution ' of γ-Fe_2O_3 and Fe_3O_4. In this case, the faint extra lines which occur with pure γ-Fe_2O_3 might be too faint for detection and the tendency of γ-Fe_2O_3 to change to the α-form might be suppressed. It is possible that both explanations apply, in view of some recent work of Richards and White,[7] which establishes the existence of unbalanced spinel solid solutions in the system Fe–O–Al.

This solid-solution effect may be responsible for the difficulty of distinguishing hematite from magnetite in polished sections of the sinters under the microscope. Although hematite should be brighter than magnetite under reflected light (the reflection percentages are 27·0 and 21·4, respectively, according to Folinsbee[8]), there is scarcely any difference in these sinters and often the shape of the grain gives the first clue to identification. For example, in most cases, as in Fig. 8, the hematite grains are rounded and resorbed (structures typical of remnant minerals), whilst the magnetite occurs as octahedral grains (Fig. 9), varying in size and completeness and formed as a primary phase of crystallization from the molten state. When present as dendrites (Fig. 10), magnetite is characterized by its more rectangular branching. Hematite of normal contrasting brightness was observed in pieces of friable sinter as an oxidation product, both around the magnetite crystals and along octahedral planes within them, as in Fig. 11 ; however, this alone does not account for the higher proportion of Fe_2O_3 in the friable sinter.

The form of the hematite and magnetite crystals indicates that much of the Fe_2O_3 initially formed as distinct hematite crystals must have reacted with the melt to precipitate as magnetite before solidification of the sinter. This has resulted in resorption of the hematite crystals and frequently in their complete disappearance—features that are more pronounced in the centre of the bed, where the material is held at a higher temperature for a longer period than in the upper layers. The early-formed magnetite has nearly completed its octahedral growth, forming crystals occasionally up to 0·05 mm. across but mostly about 0·01–0·02 mm., together with many of 0·005 mm. and less. The later-formed magnetite crystals, precipitated out in an iron-poor viscous slag, have remained as skeletal dendrites. Both these and the remnant grains of hematite are the same size. Not infrequently the magnetite crystals in the glass have a fringed outline suggestive of dendrites.

The Matrix

Typical ironstone sinter is remarkably porous, voids, both macro and micro, accounting for some 75% of its volume. Of the solid matter, iron oxide minerals actually constitute roughly one-third of the sinter by volume, although under transmitted light they appear to form a much higher proportion, as will be seen from a comparison of Figs. 12*a* and *b*.

Although melilite* and yellow isotropic glass of similar composition, together with some wollastonite ($CaO.SiO_2$) and anorthite ($CaO.Al_2O_3.2SiO_2$), should be the principal phases in the matrix, full equilibrium is not attained during sintering. Consequently, the mineral association and texture vary widely from point to point through the matrix. Some indication of these variations is given in Fig. 12. Further evidence of non-equilibrium conditions is afforded by the micro-radiographs, Figs. 13 and 14. In Fig. 13, two quite different mineral assemblages occur only 0·5 mm. apart, whilst Fig. 14 shows an association of much tridymite (SiO_2) with some anorthite and

*The solid-solution series whose end members are gehlenite ($2CaO.Al_2O_3.SiO_2$) and akermanite ($2CaO.MgO.2SiO_2$). Most of the melilite observed is close to gehlenite in composition.

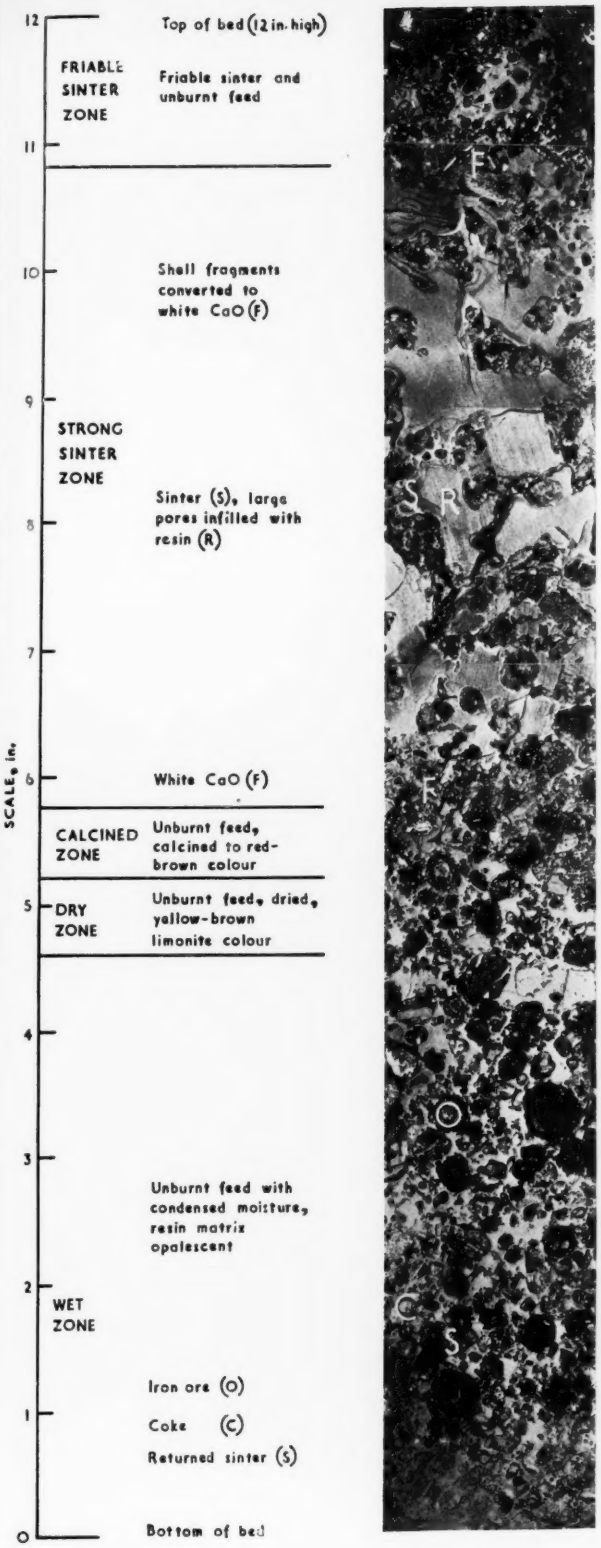

Fig. 3—Zone structure of the bed developed during sintering

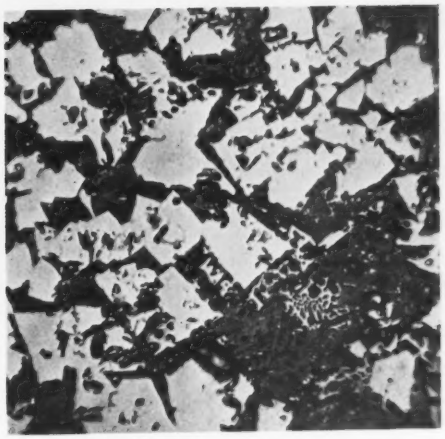

Fig. 4—Polished block showing light grey magnetite crystals in partially crystalline silicate matrix Reflected light × 400

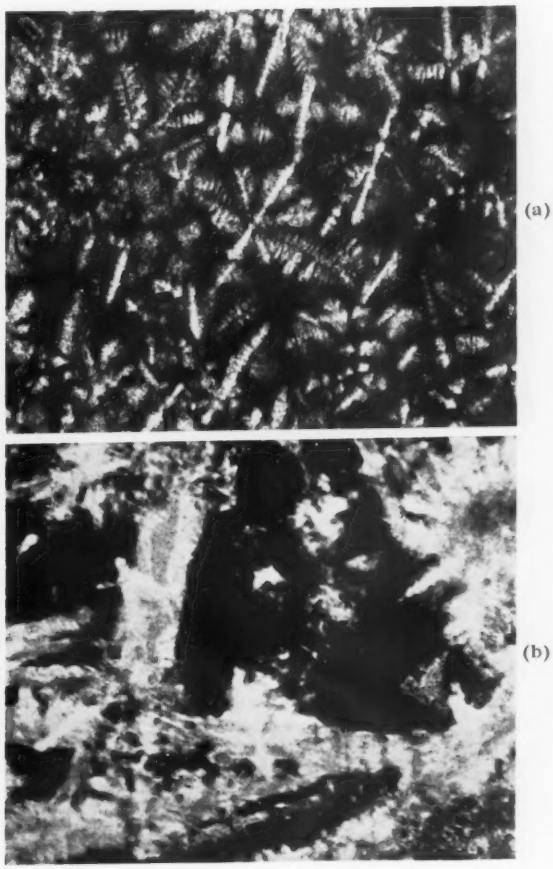

Fig. 5—Micro-radiographs of (*a*) dendrites of wüstite (FeO) in FeO-rich monticellite matrix; (*b*) wüstite laths in dark silicate matrix × 250

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[*To face p.* 320

Fig. 6—Polished section of a piece of oölitic ore enclosed in the sinter. The oöliths are largely replaced by hematite with the development of shrinkage cracks, now infilled with the sectioning resin (indicated by arrows) Reflected light × 150

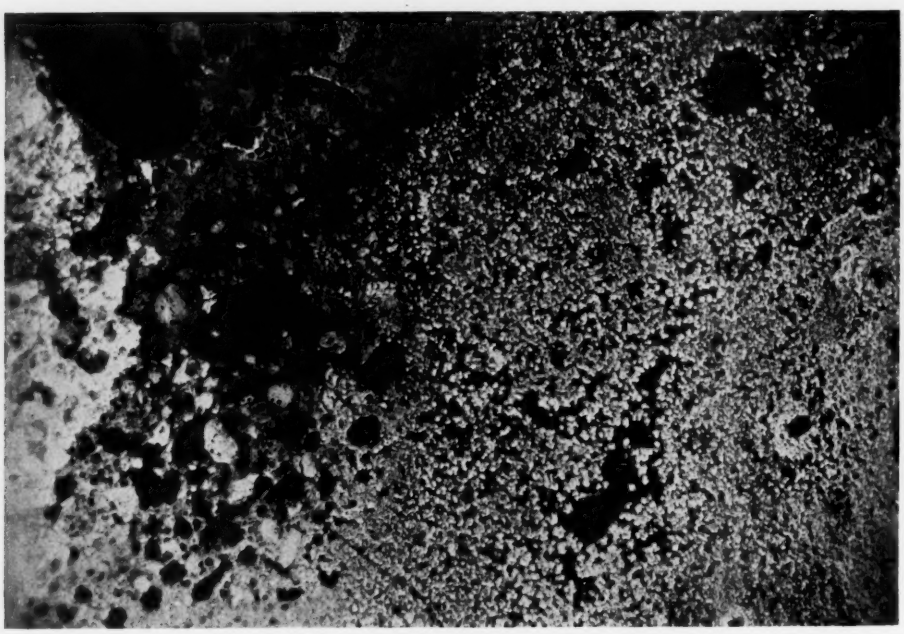

Fig. 7—Micro-radiograph showing transition from fully sintered material with white granular iron oxides (*right*) into partially sintered ore (*left*) × 40

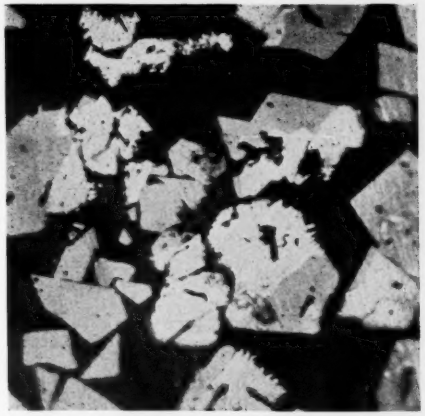

Fig. 8—Pale grey crystals of magnetite and white resorbed hematite in dark silicate matrix
Reflected light × 750

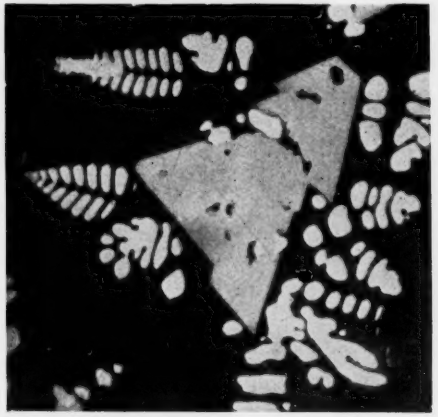

Fig. 9—Pale grey octahedral magnetite crystals and white dendritic hematite in dark silicate matrix
Reflected light × 750

Fig. 10—Micro-radiograph showing dendrites of magnetite (*M*) and hematite (*H*) in matrix of wollastonite and melilite × 250

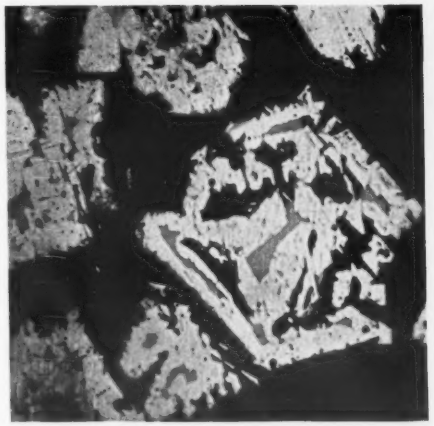

Fig. 11—Magnetite (pale grey) almost completely re-oxidized to hematite (white) and surrounded by dark silicate matrix Reflected light × 750

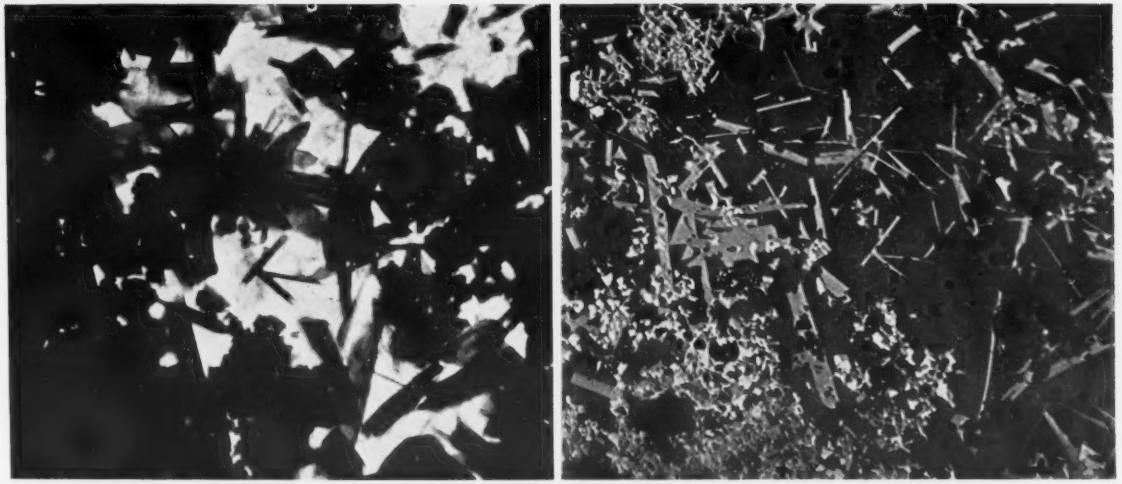

Fig. 12—Thin section of sinter: (*a*) Examined by transmitted light, showing magnetite crystals (black) in a partially crystallized matrix of gehlenite and other silicates (white) and calcium ferrite (grey); (*b*) same field as (*a*) observed under reflected light, showing magnetite (light grey), calcium ferrite (medium grey), and silicate matrix (dark grey) × 250

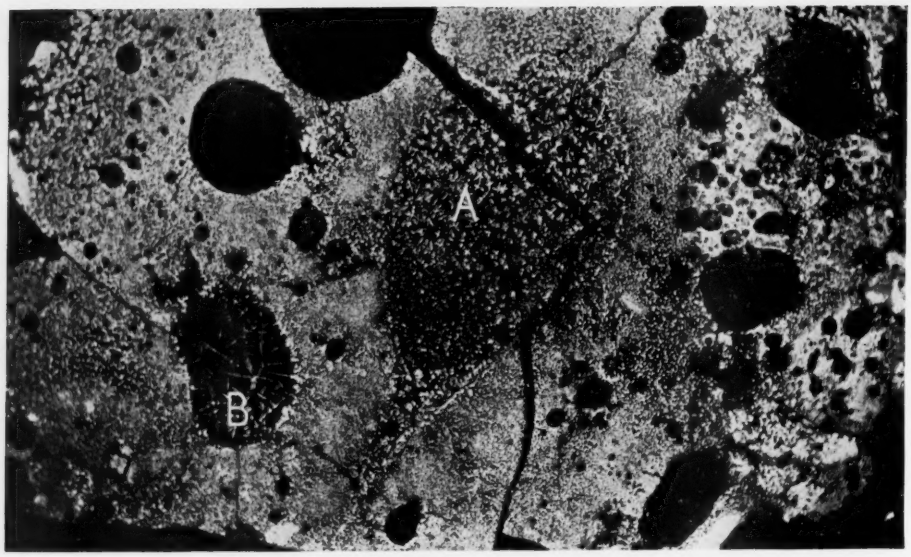

Fig. 13—Micro-radiograph of sinter showing two adjacent ' slag pools ' with different mineral assemblages. *A* = wüstite and monticellite (*see* Fig. 5*a*); *B* = magnetite, hematite, wollastonite, and melilite (*see* Fig. 10) × 40

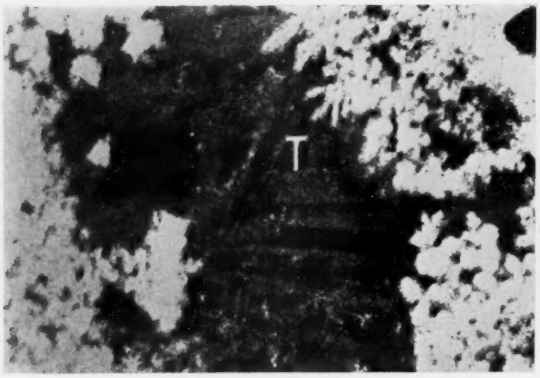

Fig. 14—Micro-radiograph showing association of tridymite (*T*) with anorthite and diopside-type silicate. A small quantity of calcium phosphate, $Ca_3(PO_4)_2$, is also present × 250

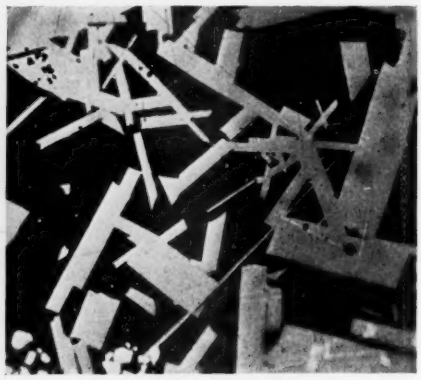

Fig. 15—Calcium ferrite crystals in dark silicate matrix
Reflected light × 750

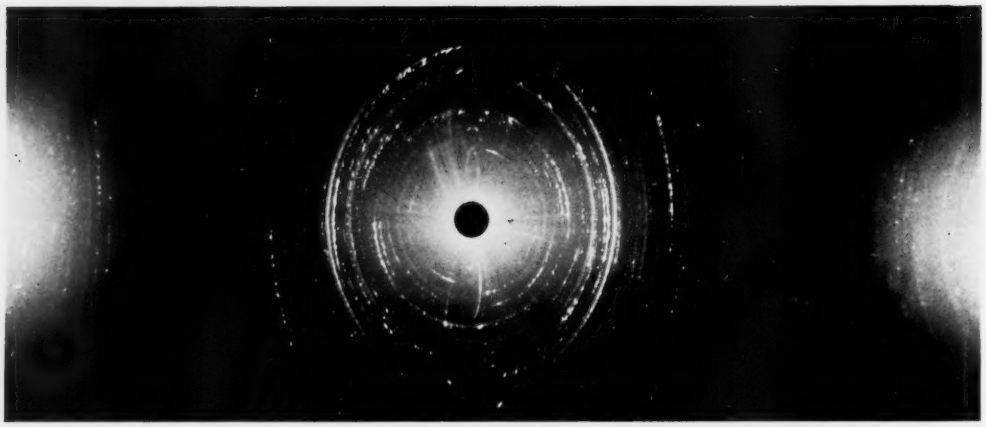

Fig. 16—Transmission diffraction pattern from region of thin section of sinter shown in Fig. 14

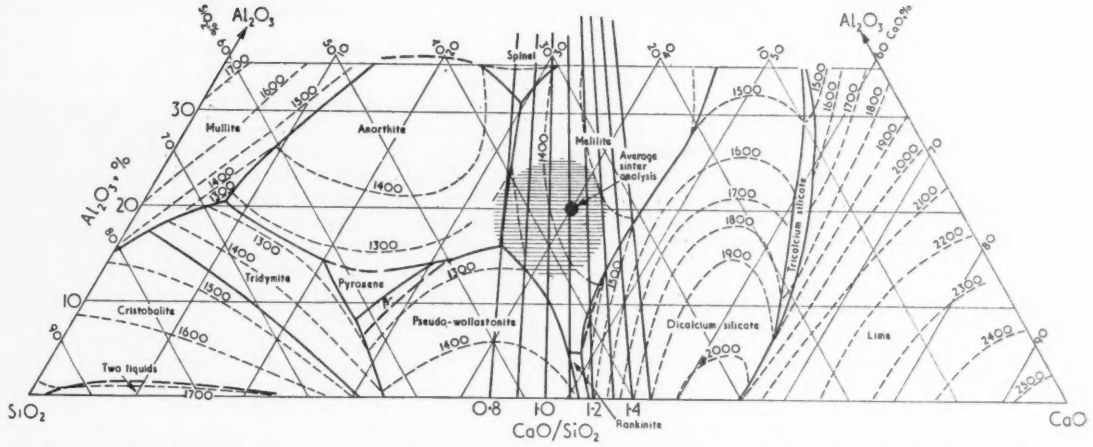

Fig. 17—Section of CaO–MgO–Al_2O_3–SiO_2 quaternary system (Osborne and others[9]) at 4% MgO, showing chemical composition of a series of representative Appleby-Frodingham sinters

pyroxene (CaO.MgO.SiO_2)—an association which would not exist at full equilibrium.

These non-equilibrium minerals have a very localized distribution. Thus, the overall content of dicalcium ferrite* ($2CaO.Fe_2O_3$) is estimated at about 3% in normal sinter, but microscope fields with up to 50% have been observed (Fig. 15). These patches generally occur in regions adjacent to remnant shell fragments. In one case, passing inwards towards a nucleus of calcined shell, a mineral sequence was noted consisting of magnetite + dicalcium ferrite + fayalite ($2FeO.SiO_2$), then magnetite + dicalcium ferrite + glass, and, adjacent to the lime, magnetite + dicalcium silicate ($2CaO.SiO_2$). In other fields, the lime silicate was probably tricalcium silicate ($3CaO.SiO_2$). Around patches of ore containing unabsorbed quartz grains, fayalite develops as a profusion of fine needles radiating from the granular iron oxides, often in a background of glass.

Other mineral phases present in small proportions in normal sinter include :

Brownmillerite ($4CaO.Al_2O_3.Fe_2O_3$), which forms a solid-solution series with dicalcium ferrite and is consequently difficult to distinguish from that mineral
Monticellite (CaO.MgO.SiO_2)
Lime (CaO), locally recarbonated to calcite ($CaCO_3$)
Calcium phosphate ($Ca_3(PO_4)_2$)
Calcium sulphide (CaS)
Pyrite (FeS_2)

When the coke content of the feed is excessive, an exceptional amount of fayalite is formed and this may be accompanied by stringers of metallic iron, although the latter are rare in the sinters examined.

Reference to the work of Osborn and co-workers,[9] on the equilibrium of the CaO–MgO–Al_2O_3–SiO_2 system, emphasizes how far the sinter matrix departs from true equilibrium. If the analyses of the sinter matrix are recalculated to the basis CaO + MgO + Al_2O_3 + SiO_2 = 100, then the MgO content of the sinters studied was about 4% ; none contained less than 3% or more than 5% of MgO. A typical recalculated average was as follows :

CaO	40%	Al_2O_3	20%
MgO	4%	SiO_2	36%

*Latest X-ray evidence suggests that this mineral is monocalcium ferrite.

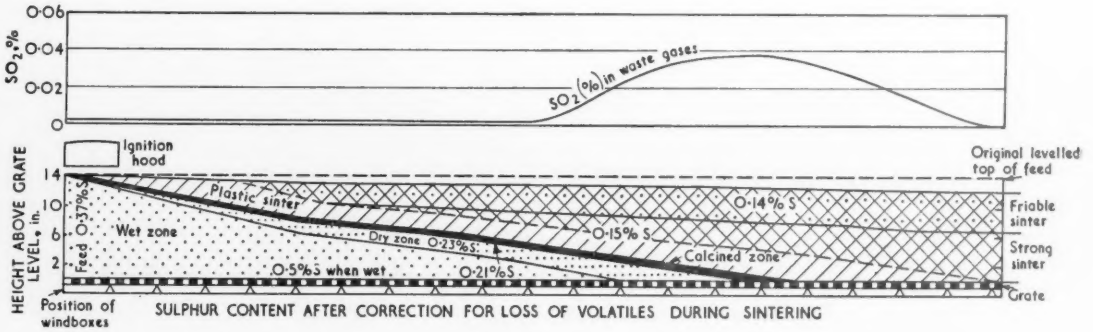

Fig. 18—Sulphur migration during sintering. (Sulphur contents expressed as percentage of original feed dried at 100° C.; '0·5% S when wet' indicates approx. sulphur content in bottom of wet zone before elimination of much of absorbed SO_2 on drying the sample at 100° C.)

It is therefore possible to simplify the comparison by referring solely to the 4% MgO plane derived from Osborn's work. A portion of this is shown in Fig. 17. The shaded area represents the scatter in chemical composition observed in a series of 216 samples. Almost all lie within the melilite field, so that the first phase to crystallize out should be melilite, and this should ultimately be accompanied by either anorthite or wollastonite, or both. The occurrence of minerals such as tridymite and tricalcium silicate indicates how far the matrix may depart from the true equilibrium.

SULPHUR ELIMINATION

In Appleby-Frodingham practice, approximately 70% of the sulphur is ultimately removed in the waste gases during sintering. Sulphur is present in the raw ore almost entirely as pyrite, although calcium sulphate is sometimes detected ; in addition, the returned sinter in the feed contains pyrite and lime-rich patches with calcium sulphide.

During sintering, much of the pyrite and some of the sulphate are decomposed, the sulphur being evolved mainly as SO_2. In the early stages of the process much of this SO_2 is absorbed in the unburnt feed, particularly in the wet zone, where it dissolves in the moisture. This absorbed SO_2 is partly driven off in the later stages of sintering, but some reacts with the constituents of the bed and remains in permanent combination.

The sulphur contents of the various zones and the analyses of the waste gases, set out graphically in Fig. 18, demonstrate this early concentration of sulphur in the lower part of the bed. Until the flame front is half-way down the bed almost all the sulphur evolved in combustion is absorbed in the underlying material.

Once the feed has been sintered there is no further loss of sulphur, even if air is drawn through the bed until it is cold, for the sulphur is now held in stable form or sealed as pyrite in the silicate matrix. Polished sections reveal minute brass-yellow spherules and blebs of pyrite finely disseminated throughout the sinter matrix. The presence of sulphide was demonstrated by a sulphur print which enabled samples to be taken for X-ray examination. Powder photographs indicate the presence of pyrite and calcium sulphide.

CONCLUSION

Ironstone sinter, as made at Appleby-Frodingham, consists of iron oxide crystals, principally magnetite, disseminated in a silicate matrix. This matrix closely resembles the blast-furnace slag formed in all-sinter practice, but has not attained such complete equilibrium. Thus, in addition to melilite, wollastonite, anorthite, and glass—constituents commonly found in blast-furnace slag—it contains many other silicate minerals, locally in abundance. Even though complete equilibrium has not been attained, it must be recognized that most of the reactions involved in the formation of the blast-furnace slag are completed, or nearly so, on the sinter strand. The blast-furnace is left to remelt this sinter slag and reduce the iron oxides.

APPENDIX
Experimental Details

Sampling

Samples of the sinter bed on the Dwight-Lloyd strand were obtained with the equipment illustrated in Fig. 19. For each sample, a perforated disc with a central rod, 13½ in. high, was placed on the grate, 2 ft. from the side, just before it passed under the swinging spout. Ten such discs were laid at equal distances along the strand. When the first had almost reached the discharge end, the strand was stopped and the suction was shut off. The sample positions were indicated by the tips of the rods emerging above the sintered bed. Mild-steel pipes of 6 in. dia. were driven around each central rod and the cylindrical section of the bed was withdrawn from the strand. The depth of sintering at each sampling position was measured by a scorch mark on a wooden lath placed in the hole in the bed.

Sections withdrawn from the bed were stored in air-tight tins for later chemical analysis ; some of the sinter was used for making thin sections. The run was repeated and the fresh pipe samples were set in Marco Resin S.B.26*C*. These were sawn into blocks (13 × 1½ × ¾ in.) from which thin sections were cut vertically, representing the continuous changes from unburnt feed to sinter. Polished sections were made from portions chosen at random from the vertical face of the block after re-setting in Bakelite. The usual petrological and metallurgical sectioning and polishing techniques were employed.

In the laboratory unit, a sample of the bed was obtained in a trough-shaped steel section placed vertically in the sinter box, isolating one corner ; the trough section was removed with the opened box lying on its side. The centre of this section was not affected by the abnormal burning that occurs at the

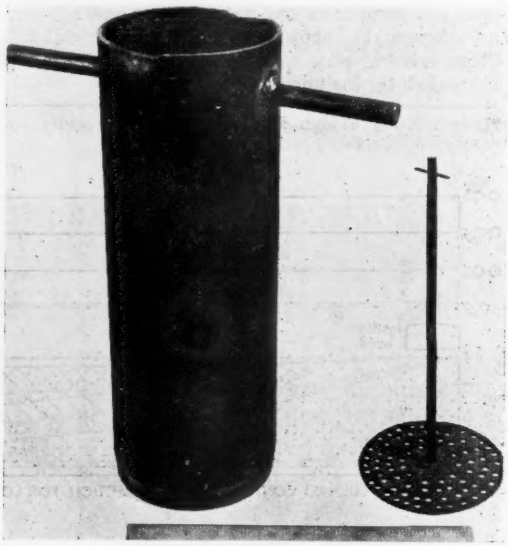

Fig. 19—Equipment for obtaining vertical samples through the bed on the Dwight-Lloyd strand

sides of the box, where shrinkage allows the easier passage of air, and was used for measuring the zones.

Petrological Technique

The opaque iron oxides and transparent silicate matrix of the sinter could only be satisfactorily studied by a combination of transmitted-light and reflected-light methods. Figure 12 illustrates the effects obtained when the top of a thin section was polished and the same field was examined by both methods. Under transmitted light, the magnetite appeared opaque whilst the transparent slag matrix was determined as crystalline silicate and isotropic glass. Under ordinary reflected light, the magnetite showed white against the dark grey background of less-reflective slag, in which only a faint trace of the crystal structure was revealed. The structure of the silicates was brought out remarkably well under crossed nicols, using reflected polarized light. Comparison of the photographs shows the false impression of the relative proportion of iron oxides and silicates obtained from a normal thin section (approximately 0·03 mm. thickness) in which the opaque minerals below the surface prohibit accurate surface distribution. A better polish for reflected-light examination was obtained on bakelite-set polished blocks, used for normal study.

X-Ray Examination

The X-ray examination was carried out to confirm or amplify the information obtained from the petrological work. The first stage of the X-ray investigation involved the identification of constituents by powder photographs, assisted by a series of standard photographs. Since the two oxides Fe_3O_4 and Fe_2O_3 formed the major part of most of the samples, the proportion of these two oxides was estimated. For this purpose, photographs of the following standard mixtures were produced :

Fe_2O_3, %	100	80	60	40	20	0
FeO, %	0	20	40	60	80	100

To estimate the amount of gehlenite, two standard mixtures of Fe_3O_4 and gehlenite were also prepared :

Fe_3O_4, %	75	50
Gehlenite, %	25	50

The oxide Fe_3O_4 was used rather than Fe_2O_3, since most of the sinters contained considerably more of the latter. The relative amounts of other constituents were estimated on the basis of previous experience with mixtures of this kind. It is stressed that the relative proportions indicated can be only approximate, even with the assistance of standard mixtures, owing mainly to the widely varying degrees of crystallinity and grain size which are found in sinters.

Micro-Radiography and Supplementary Diffraction Technique

The knowledge derived from X-ray powder photographs[10] usually gives no information on the shape or form of the oxide grains, the grain size, the presence of voids, etc., and only indicates the average constitution represented by the phases present in considerable quantities. As has been pointed out in the petrological examination, the sinter is really very heterogeneous.

Useful supplementary information can be obtained by means of microradiography, the principles of which are well known.[11, 12, 13] In the second stage of this investigation, therefore, the specimen, a thin section of the sinter, was placed in a small camera constructed for the purpose, and was exposed, in contact with a piece of Kodak Maximum Resolution Plate, to nickel radiation. On developing the plate, the regions of high iron content appeared light, because of the strong absorption of the nickel radiation by the iron atoms.

The sinters examined by this method were taken from those already surveyed by means of X-ray powder photographs, and were from one of the blocks of sinter from the works plant. A number of regions were examined at a comparatively low magnification (×40), and selected regions were then studied at a higher magnification (×250). In some cases, the identification of constituents was facilitated by taking an X-ray diffraction photograph of the thin section itself in a region selected because of some special features shown by the micro-radiographs. This necessitated the use of a fine collimator system. One of these diffraction patterns is shown in Fig. 16.

Acknowledgments

The authors acknowledge the courtesy of Mr. F. H. Saniter, Director of Research, for permission to publish this paper, and they thank all who have provided practical assistance and encouragement. Special thanks are due to the Ore Mining Branch, Colsterworth, for the analytical data, and to Mr. F. B. Pickering, whose work on polished sections of sinter has been incorporated in this paper.

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DISCUSSION ON PAPERS

DISCUSSION AT MEETINGS · WRITTEN CONTRIBUTIONS

AUTUMN GENERAL MEETING, 1953

THE AUTUMN GENERAL MEETING of THE IRON AND STEEL INSTITUTE was held on Tuesday and Wednesday, 24th and 25th November, 1953, at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1. The President, Mr. JAMES MITCHELL, C.B.E., was in the Chair, except during the afternoon of the first day, when his place was taken by Mr. RICHARD MATHER, Past-President.

Sessions were held from 2.15 P.M. to 5.15 P.M. on the Tuesday and from 9.45 A.M. to 1.15 P.M. on the Wednesday. Buffet luncheons were provided in the Library of the Institute on both days.

The Report of the Meeting was published in the March issue of the *Journal*.

Joint Discussion on the Papers—

THE EFFECT OF EMISSIVITY AND FLAME LENGTH ON HEAT TRANSFER IN THE OPEN-HEARTH FURNACE*

By M. W. Thring

EXPERIMENTS ON FLAME RADIATION IN AN EMPTY OPEN-HEARTH FURNACE†

By W. P. Cashmore and M. W. Thring

THE LENGTH OF OIL AND GAS FLAMES‡

By A. L. Cude

Professor **M. W. Thring** (Sheffield University), Mr. **W. P. Cashmore** (Guest Keen Baldwins Iron and Steel Co., Ltd.), and Mr. **A. L. Cude** (I.C.I. Ltd., Billingham Division) presented their papers.

Mr. **R. W. Evans** (Steel Company of Wales Ltd.): These papers remind us of the intense attention that is now being paid to the question of the transfer of heat from flames to liquid and to solid phases, not only in the U.K. but in Europe and in the United States, although the greatest attack on the problem is coming from Great Britain.

These three papers are in many ways complementary to one another. Professor Thring has achieved what I would consider an almost impossible task. He has not only calculated mathematically the time that it takes to melt a charge, but has also added the roof temperatures that prevail during the process.

It is quite true that certain simplifying assumptions have had to be made, but that was absolutely essential in the present state of our knowledge, because without them the problem could not have been tackled mathematically at all. Professor Thring has said that he does not tell us absolutely what happens in the furnace, he does not give us the absolute answers; but he is trying to tell us comparatively what happens; and there is no doubt that as we get to know more about slag, conductivity, and various other thermo-chemical reactions and factors in the O.H. bath, we shall be able to take this method of calculation further still.

In the paper by Professor Thring and Mr. Cashmore, we see the second step taken, *i.e.*, the attempt to show, by altering levels of steam quality, oil temperature, and steam/oil ratios how best one may endeavour to achieve the radiating flame which Professor Thring postulates in his first paper. In other words, the second paper gives us a lead on how to fit the variables to give the required transfer of heat.

* *J. Iron Steel Inst.*, 1952, vol. 171, pp. 381–392.
† *Ibid.*, 1953, vol. 175, pp. 177–182.
‡ *Ibid.*, 1953, vol. 175, pp. 304–312.

In Mr. Cude's paper, a relationship has been sought between the quantities and velocities of air and fuel delivered to the furnace and the flame length, and, to establish those relationships, the empirical coefficients for given burners have been introduced and verified.

In all these matters one must bear in mind that the ultimate aim is to produce economically more tons/hr. To examine how important flame character is in regard to tons/hr., I have compiled a statistical table showing the rate, the charging, the melting, the refining, the fettling, and the furnace availability, and also the four major conditions in an open-hearth plant which affect those things.

The first, which I call, for lack of a better name, logistics, is concerned purely with the servicing of the O.H. furnace, *i.e.*, delivering to it the raw materials and taking away the melted charge on the pit side. Another is the flame character. The third is the quality of the raw materials. Fourthly, there is the quality of the steel to be produced. I will try to apply these to a modern melting shop in which the logistics have been properly worked out and the furnaces can be served adequately with the apparatus available.

The logistics affect the charging vitally, but they do not affect the melting so much or the refining or the fettling, or, for that matter, the furnace availability. The flame character affects the charging, the melting and the refining; it does not affect the fettling, but it affects the availability. With regard to quality of the raw materials (and here I am talking about the chemical quality, such as the difference between a high-phosphorus and a low-phosphorus iron—the latter can be charged as fast as the former—rather than of the size of the material), on melting it does not make a great deal of difference; on refining it certainly does make a difference, as it does to fettling and to the furnace availability. Finally, on steel quality, one can charge the bath for a good-quality steel probably as fast as one can for the low quality; so it does not affect the charging or the melting, but does affect the refining and fettling and the furnace availability.

Thus the table is as follows:

	Logistics	Flame Character	Raw Materials	Steel Quality
Charging	Yes	Yes	No	No
Melting	No	Yes	No	No
Refining	No	Yes	Yes	Yes
Fettling	No	No	Yes	Yes
Availability	No	Yes	Yes	Yes

I will, for the moment, assume that all the ' Yes's ' are more or less equal in effect; actually, they are not. It might be said that the ' Yes ' for the charging overtakes all the rest, but if there is not a good flame, there is no point in charging the furnace first because you cannot melt it. Under logistics, there is one ' Yes '; under flame character there are four; under raw materials there are three; and under steel quality there are three.

Looking at the O.H. process as a whole, the flame is approximately equivalent to 37% of the operation of the furnace; so that when we are tackling the flame we are really tackling the biggest part of or the biggest factor in determining output. It is most important to bear in mind constantly the question of the effect of what we are trying to do here on the tons/hr. and the economics of the process.

This table could be greatly enlarged—*e.g.*, under flame character, one could put long flames and short flames—but it will serve.

Professor Thring admits that there is no known method at present of preserving the luminous emissivity of a flame right along the bath if there is quick combustion. These two things are incompatible: a very fast-burning flame cannot at the same time be highly luminous, because the luminosity is given by the small particles of carbon and is lost when they are burnt up quickly. The only way in which emissivity of the flame might be preserved right along the bath is as Professor Thring suggested, *viz.*, small wisps of carbon particles might be injected along the furnace. High-temperature flames are in general not highly emissive; for melting scrap, the former quality is essential, the latter not. In one furnace I have known no illuminant could be seen, but it was a very fast melter. Even when the charge was under cover of the slag, provided that the carbon was not high, the flame, although it was quite invisible, could melt the bath clear very quickly; but if the bath melted with over 0·40% of carbon the slag became very frothy and there was no way of cutting down the froth without luminosity. That flame was not radiating in the ordinary sense at all; or rather, it was radiating on the invisible but not on the visible bands; it was evidently able to produce the highest rate of transfer of heat by convection.

The flame character probably has a vital effect on the chemistry of the charge. Some flames will oxidize the charge much faster than others. When putting very high volumes of oil into an O.H. furnace, it is possible to oxidize the charge much faster than would be possible in a producer-gas-fired furnace, probably because of the very great entrainment power of the oil jet. The amount of pig iron that one has to carry in a fast-driven oil-fired furnace to melt the charge completely is far greater than in a producer-gas-fired furnace.

The roof temperature can be calculated in different zones longitudinally along the furnace, but this gives the average temperature across from front to back in that zone. My experience has been that the back tends to be hotter than the front. If, when calculating the average temperature at a point one-third or one-half the distance along the furnace, it is concluded that the temperature is safe, one must make quite certain that that is the temperature at the back as well as at the front.

The suction pyrometer is probably the most useful instrument nowadays on an O.H. furnace. High preheats are essential to work the process economically, and without a good suction pyrometer one does not know whether there is a high preheat or not. Sighting a radiation pyrometer on top of the checkers does not give us any real information; but knowing the preheat of the air entering the furnace body alongside the flame of oil is very important. Many people would be astounded to see how the furnace performance does vary with the preheat of the air that is being put into it.

The experiments described by Mr. Cashmore and Professor Thring were a very good example of a neatly planned factorial trial. They gained the maximum amount of information by doing the least amount of experimental work. However, the absence of charge in that furnace may have affected the experiments. For instance, the authors speak about the lack of flame ' sting ' on the end doors and presume that this was due to the furnace pressure instrument possibly not being right; this might happen in an empty furnace but if the furnace had been charged and the flow through the furnace had been altered by the position of the charge in the furnace, there might have been a different result. What difference does Mr. Cashmore think the emptiness of the furnace made ?

Has Mr. Cashmore been able, on a furnace which is working and melting, to achieve higher tons/hr. than before by taking advantage of what he found out on the empty-furnace experiment and applying it to a full one ? That, after all, would be the proof.

I should like to ask Mr. Cude the following: If one takes an outside atomizer on a big furnace which is burning up to 500 gal./hr. of oil, with an initial steam pressure of 150 lb./sq. in., delivering the atomized mixture through a 1-in. dia. tube, and an oil pressure at the outside atomizer of 120 lb./sq. in., what would be the length of the flame ?

Dr. **J. H. Chesters** (United Steel Companies Ltd.): These papers fit very neatly into a much larger picture that will in due course enable us to calculate a great deal about furnace design and operation without even going near an actual plant. We still feel that the logical starting point in design is the flow pattern within the furnace chamber and that the greatest weakness at the moment is our inability to state precisely what kind of flow pattern we desire. We all realize that there must be enormous turbulence adjacent to the scrap pile if we are to get both rapid combustion and efficient heat transfer, but we also would like to see the rather contradictory condition of zero flow at the walls. We feel that the position will best be clarified by proceeding to extend on the one hand our knowledge of flow in simple shapes, and on the other hand making those simplifications in actual furnaces which can be introduced without loss of efficiency, *e.g.*, elimination of unnecessary knuckles and monkey-walls, and the use of single uptakes, slag pockets, and checker chambers, instead of the double variety. Once we are able to appreciate the flow pattern aspect all the way from the simple shape through to the complex designs of existing furnaces, we shall have a sound basis on which to build the furnaces of the future.

Mr. Cude's paper extends our knowledge of mixing substantially beyond that already available, and thus helps to make quantitative this aspect of flow in furnaces. I was particularly interested in Mr. Cude's suggestion that the heat should be released near the point at which it is to be absorbed. We have been making certain rather radical experiments lately with 'sawn-off jet engines,' both for heating ladles and for melting steel, and have become very conscious of the importance of geography. If fuel can be burnt in a very small space, temperatures close to theoretical can be achieved, but if the gases have to travel a substantial distance before arriving at the charge much of the value of this intense combustion is lost by radiation to refractory surfaces and the like.

Turning to the radiation pattern, which arises from the flow and mixing patterns, the amount of work done, particularly at Ymuiden, is so great as to be almost overwhelming. Even so this work is still at an early stage, for we know very little for example about the effect of such important factors as preheat.

Guest Keen Baldwins Iron and Steel Co. are to be congratulated on investing quite a substantial sum of money on the experiment described by Professor Thring and Mr. Cashmore. It is only by such bold experiments that we shall be able to relate the fundamental data obtained at Ymuiden to steelworks practice, and if the results obtained are as significant as they at present appear, the investment should soon prove to be a good one. In this connection I would like to ask just how much reliance the authors place on their superheat data. It is surprising to me that a change from 85% dry steam to only 8° F. of superheat should show a radiation increase of about 10%. Previous experience* suggests that a 10% increase in radiation might be worth as much as 30 min. on tap-to-tap time. If steam superheat can play as vital a part as this suggests then we should not be discussing it but rather be busy fitting superheaters. Many people have stated that superheat is important, and presumably say so on the basis of actual experience. It would be a real service if they would provide actual quantitative data showing the improvement obtained by its use.

One detail question I would like to ask is: How were the radiation instruments located ? Were they merely sighted through holes in the doors along a horizontal plane, or were they deliberately adjusted so as to indicate the peak flame radiation at that distance from the burner ? Further, how would the authors, given radiation measurements obtained by traversing the flame at each of five doors, set about assessing the flame power and comparing it with similar data for another furnace ?

On the question of convection as discussed by Mr. Evans, I would like to put in a plea for a more balanced point of view. A few years ago many of us were saying that 90% of the heat transfer to the charge in an O.H. furnace was inevitably by radiation. Judging from certain discussions I have listened to recently there is now a school of thought which suggests quite the opposite, *viz.*, that about 10% is due to radiation and 90% due to convection. I suggest that the truth is somewhere in between these extremes, and until more specific data become available we should keep an open mind on this subject. We do agree, however, that there is a real discrepancy between the Ymuiden work and our experience of open-hearths, in that the latter seem to work better with more steam, while the Ymuiden results show lower radiation whenever steam is increased. A great deal of information is now available regarding the relation between steam pressures behind the nozzle, steam flows, and air entrainment, and it is increasingly clear that big improvements can be obtained in many shops merely by improving the plumbing, *i.e.*, getting behind the final nozzle a far higher steam pressure, by reducing pressure drops between this point and the boiler.

Mr. **A. Aitken** (Colvilles Ltd.): There are some primary questions that I should like to ask the authors.

(1) What type of burner was used in the trials ?

(2) Does steam pressure mean line pressure or pressure at the burner tip ?

(3) What effect on the observations would theoretical furnace pressure (nil at sill) have made ? I would suggest that some differences as shown in the curves would have been eliminated.

(4) With only 8° F. superheat, was there no possibility of the steam being wet by the time it had mixed with the oil ?

(5) The suggestion by the authors that the optimum steam/oil ratio is greater with cold oil is no doubt true, but how much of the higher peak radiation with cold oil may be coming from the greater weight per unit volume if the method of metering were the same for both temperatures ? This may mean a difference of 5% in the heat energy used between hot oil and cold oil for the same metered figures.

However, we have all been reassured from these results that for the ultimate radiative power of a flame we should use hot oil, rather than cold oil; superheated steam, rather than wet steam; and optimum steam/oil ratio.

But these are not the only considerations in actual practice. The results of this paper are more readily applicable to hot metal practice than to cold metal practice simply because a flame of high radiative power is necessary for a much longer period with hot metal.

We find that with our cold-metal practice a flame carrying 8–10 lb. of steam per gal. of fuel allows us to cut down much more quickly, and it is only after the bath

* J. H. Chesters and M. W. Thring, Spec. Rep. No. 37: 1942, London, The Iron and Steel Institute.

is flat and clear that we need this highly radiative flame. When our bath melts clear, the bath temperature is about 1600° C. We have found, too, that we make better-quality steel when the bath does not exceed the specified tapping temperature of the steel being made, and as these tapping temperatures are in the region of 1600° C. all we need do, once the bath is clear, is to keep the furnace hot and let the intrinsic heat from bath reactions take care of the radiation loss through the hearth.

Consequently, for three-quarters of the process time we need a flame giving us maximum convective heat transfer, and for the other quarter a highly radiative flame. In hot-metal practice where the bath is liquid much earlier and at a much lower temperature, the highly radiative flame is of much greater moment and it will pay operatives to give close attention to the authors' results. However, as I have said, the highly radiative flame is not the only important consideration, and much work remains to be done on convective heat transfer to give increased productivity and fuel efficiency.

One interesting point in the authors' paper that bears repeating is the enormous effect that preheat plays in increasing heat transfer through higher flame temperature. Design of checker work and furnace ends as well as checker brick quality has been static for decades. Close inspection of these vital parts will be invaluable if average preheats could be raised even 100° C.

The time is ripe for the industry to engage co-operatively in pilot-scale plants where expensive fundamental projects such as this may be carried out for the benefit of the industry as a whole instead of one single firm bearing the brunt of the cost.

Dr. **A. H. Leckie** (B.I.S.R.A.): How valid are Professor Thring's calculations in practice? During charging, when the charge is cold, convection is probably the more important factor. During the melting period, undoubtedly radiation plays an important part, and Professor Thring's calculations are most nearly applicable. I could not quite gather from his paper what his views are about the refining period, but during this period there is appreciable heat of chemical reaction originating in the bath, and heat transfer from the flame is not the only thermal phenomenon taking place.

Thus, if we consider the actual melting-down period as the one for which Professor Thring's remarks are really valid, this covers only about one third to one half of the charge. I therefore feel that these calculations have to be regarded in that light—they are applicable to part of the charge only and we need to be a little careful before we say that the design of a furnace can be based on these calculations. The calculations are, however, an important contribution to the difficult task of designing a furnace on a sound fundamental theory.

Professor Thring has rightly emphasized again that a higher thermal efficiency does not necessarily go with a very high output.

The main criticism of the paper by Mr. Cashmore and Professor Thring is that there was no heat 'sink' in the furnace during the trials. I suggest that if the work is ever repeated there should be some water tanks (acting as calorimeters) that could be inserted through the doors at the beginning of the trial and so provide a heat 'sink' which would give some measurement of heat transfer.

Some dangerous inferences can be drawn from reputed correlation between high preheat and output, in that some other condition may intrude. High preheat can be obtained in a bad way as well as in a good way, namely by burning fuel in the outgoing checkers, and making them very hot. Thus preheats of 1300° C. are not always praiseworthy.

Mr. **R. H. Baulk** (Samuel Fox and Co., Ltd.): The greatest criticism of Professor Thring and Mr. Cashmore's experiment seems to be the lack of a charge in the furnace, but that was done to get rid of as many as possible of the variables that are inherent in O.H. furnace work. Have the authors tried to determine the effect of slag level on the aerodynamic conditions in the furnace by the use of Perspex models?

The use of superheated steam enabled the authors to get a 10% increase in radiation. Over the last six weeks we have been conducting an observed trial on a furnace using normal wet steam one week and superheated steam the following week. The amount of superheat used varied throughout the test period, but averaged 10° F. This is a little greater than that used in the authors' work. However, the results have shown no improved performance at all.

How did the authors obtain their superheated steam? So far we have done this by means of a coiled pipe in the flue before the waste-heat boiler. This means that a considerable amount of superheat is lost before the steam reaches the burner. Furthermore, the steam pipe to the dead end carries a greatly reduced flow and so doubtless a certain amount of condensation must occur. It is conceivable, therefore, that after reversal and full steam flow is restored, there is a liquid film on the pipe surface, even though superheated steam is flowing. If this is the case, then the effect of superheating would be greatly reduced. Can the authors suggest an alternative method of superheating the steam to overcome this difficulty?

The authors state that the radiation from a flame is reduced by the use of steam. On the other hand, increased steam flow is known to produce a fiercer flame and faster melting. These two effects would appear to work in opposition.

Surely there must be some compromise point at which the total heat transfer due to both radiation and convection is a maximum. It would be interesting to see some curves showing how the convection as well as the radiation varies with steam/oil ratio. This stresses the urgency of having an instrument which can measure convection so that it can be studied as thoroughly as radiation has been.

Mr. **A. B. Pritchard** (Shell-Mex and B.P. Ltd.): Mr. Cude's formula will be of value not only to furnace designers (who, I suggest, should not be the works engineers), but also to fuel engineers like myself, whose job it is to investigate the operation of furnaces and try to find out the causes of unsatisfactory performance.

Before the formula can be applied to a particular case, a value for the constant must be determined, and it is here that some difficulty will be experienced, as that value will be affected by so many variables, particularly when considering oil flames.

The author states that "oil must be evaporated before it will burn" and "provided that the spray is fine enough, evaporation proceeds at a greater rate than combustion." These statements are rather too sweeping and are probably influenced by the fact that the experimental work was carried out on gas oil, which is very readily vaporized, or in furnaces where the ambient temperature was high enough to substantiate the proviso.

The formula is based on the assumption that the speed of combustion is controlled by the rate at which the air required for combustion is entrained into the fuel spray; but I think it is known that a droplet of fuel oil takes a definite time to burn, depending on its size and surrounding temperature as well as the availability of the necessary oxygen.

From my experience I would suggest that in many cases the quality of atomization of the oil will have an

overriding effect on flame length, especially when heavy fuel oils are used where the ambient temperature is relatively low, such as in boiler firing.

In these cases the value of the constant will vary for each individual application, depending on such things as the oil temperature in the burner, the efficiency of the air/oil mixing arrangements, the amount of refractory support and even the position and extent of uncontrolled air infiltration, these factors being apart from the mechanical condition of the burner.

It is in such cases as these that some of the conclusions given in the paper probably do not apply; I refer to the statements that, firstly, increasing the flame temperature, and secondly, increasing combustion air temperature, will lengthen the flame. From my own experience both of these treatments are in some cases very effective means of accelerating combustion and shortening a flame.

I do not agree that for otherwise comparable conditions the effects of burner design are not large. Mr. Cude was probably fortunate in that his experiments were carried out with two oil burners which are recognized to be good atomizers. In many cases burners of unsuitable design will have a very marked effect on combustion conditions, including flame length.

With high-temperature furnaces, the basic assumption on which the formula is based is probably as true for oil as for gas for all practical purposes, although even here Mr. Cashmore and Professor Thring infer that the quality of atomization plays some part in the rate of combustion.

With Mr. Cude's help, I have examined data obtained from some of my own observations on O.H. furnaces, and in six cases the value of the constant was between 900 and 1100. I am afraid that greater accuracy was not possible, because the data were not taken with a view to being applied to this work, but were just obtained incidentally in looking up the records. In each case the relevant pressures and temperatures were taken at the burner, and I should like to take this opportunity of suggesting that if anyone here intends to check up on the K value which I have just quoted, he must make the measurements at the burner and not take them from gauges on the panel, as these far too often do not give any indication of the true conditions owing to inadequate branch lines between the instrument panel and the furnace.

I do not doubt that the factors I have outlined can be taken into consideration in the value given to the constant, but if use is to be made of the formula an accurate assessment must be made of the effect of the quality of atomization, the grade of fuel oil, and the method of its application—and here again I would refer to the previous paper, in which it is stated that the different absolute results were obtained from each end of the furnace, showing that on the same furnace K values may well vary from end to end, let alone between apparently similar furnaces.

CORRESPONDENCE

Mr. **C. H. Bacon** (John Summers and Sons Ltd.) wrote: Measurement and assessment of the factors that influence the radiating power of the flame in an O.H. furnace are of vital importance in obtaining optimum conditions for fast working.

The authors have adopted a most interesting technique to determine the degree of the effect of some of the variables upon flame radiation, which eliminates many of the difficulties encountered in trying to measure flame radiation under operating conditions.

Unfortunately, the opportunities for making a trial of this nature are very limited, and one can only regret that time did not allow measurements to be made at more than two levels of the variables.

It is stated that 2–3 hr. were needed to reach steady conditions after a change in operating conditions. Presumably the greater part of this time was taken up in reaching steady checker temperatures, as one would expect the roof temperature to stabilize fairly quickly. As no relation was found between checker temperatures and the variables, would the authors consider that, in a subsequent trial, reliable results could be obtained without the necessity to wait for steady checker temperatures ?

I should also like to ask for the positions in the roof, at which the roof pyrometers were sighted, and whether the temperature gradient along the roof, as measured by roof pyrometer, was found to be related to the gradient of the flame.

The increased flame radiation measured when using the lower steam/oil ratio would indicate the flame condition for better heat transfer in the later stages of the heat, when radiation is the prime factor. Reference is made to earlier trials, when more rapid working was reported with the use of higher steam/oil ratios. Surely this need not be taken as a contradiction, as the effect of the higher steam/oil ratio could be expected to be experienced during the charging period, when convection must play a large part in heat transfer, and the greater momentum of the flame with higher steam/oil ratio would increase heat transfer by convection.

The indications would seem to support the use of a high steam/oil ratio during the early stages, and a low one later, particularly when coupled with higher oil temperature.

Mr. **A. T. Peters** (Round Oak Steelworks Ltd.) wrote: Mr. Cashmore and Mr. Thring must be congratulated on the very high levels of significance obtained in an experiment under non-laboratory conditions. It might have been, however, interesting to measure, and make corrections for, the back radiation of the furnace interior (back wall) by taking readings without flame, *i.e.*, during reversals, and subtracting figures thus obtained from corresponding readings 'on fuel.'*

I suggest that:

(1) The drop of radiation of a flame from the incoming to the outgoing door is even greater than that shown by the authors, for back wall radiation increases the reading of a pyrometer sighted on the thinner, somewhat flickering flame in the outgoing door to a stronger degree than in the case of a pyrometer sighted on a thick, non-transparent flame.

(2) Differences between the north and south ends may be due to differences in surface condition, *i.e.*, different emissivities of the respective parts of the back wall.

AUTHORS' REPLIES

Professor **Thring** wrote: It is often said that convection is more important than radiation in the O.H. furnace, but so far no proof has been given that convection could play even a comparable rôle to radiation, except when the scrap is piled up in the furnace and the flame is playing through it. In that period, it is clear that convection is very important; but once the bath is melted flat, there is no evidence at the moment that the mechanism of heat transfer is anything else except straightforward radiation.

* M. J. Bradley, *Amer. Inst. Min. Met. Eng., Proc. Nat. O.H. Comm.*, 1945, vol. 28, p. 310; A. L. Hodge, *Ibid.*, 1945, vol. 28, p. 322; A. J. Fisher, *Ibid.*, 1944, vol. 27, pp. 107–120.

I consider that the calculations in my paper apply to the refining period quite well. The calculation shows quite clearly that in that period the heat-transfer coefficient does not matter, but it does matter to have very slow combustion.

Various speakers have mentioned the importance of trials on actual furnaces, and I hope very much that this work will be followed up with proper measurements on real furnaces, preferably factorial experiments with controlled variables. The flame length, the emissivity, the kind of fuel, and the preheat must be varied in a series of charges, while the fuel consumption and melting time for each charge are measured.

If Dr. Chesters lets us have the measurements which he mentioned, we will calculate from them the relation between the radiation measurements and the theoretical output of the furnace.

I agree with Mr. Evans that taking an average roof temperature from front to back in each zone is an oversimplification, but the simplified theory is something to get on with.

Finally, on the question of preheat, I think we shall go as far as we possibly can at Ymuiden, subject to the proviso that we are going to preheat with recuperators and not regenerators. I frankly do not see how one can do this sort of trial with a regenerator on the furnace giving constantly varying preheat.

Mr. **Cashmore** (in reply) wrote: I cannot tell Mr. Evans what the effect was of an empty bath on the pressure distribution in an O.H. furnace. In regard to the use made of the results of the experiment, although these have not been applied directly, they have removed some misconceptions, and focused attention on the study of what now appear to be more important factors. As a result of this, furnace production and fuel consumption have benefited greatly, although such improvement has certainly not been due to research alone.

I wish in particular to direct attention to the effect of the flame on the bath, apart from the transference of heat. If no boil exists in the bath, then little or no heat can be transferred from the flame, presumably because of the absence of turbulence in the bath and in the slag. A flame giving higher radiation may possibly, therefore, have a detrimental effect in practice if its character is such that it adversely affects the rate of oxidation; *i.e.*, the rate of heat transfer to the bath depends on the rate of oxidation in the bath, and *vice versa*. Thus, it may be unwise to assess the practical value of a flame on the basis of its radiation only, without taking account of its effect on the oxidation rate of the bath. This may be the explanation of the benefit derived in practice from the use of increased steam/oil ratios, although the latter appear to reduce the radiating power of the flame.

Also, it is generally assumed that the bath is able to accept heat equally at all points of its surface. This is certainly not true when the bath is clearing, if the variations in the degree of boil, and the character of the slag, are any indication; the same may also be true to a lesser extent during refining. It is suggested therefore that there may be some focal point at which the bulk of the heat and oxygen transfer to the bath occurs, at some stages of the heat at least.

This point is made, not to belittle the importance of flame radiation results, but to emphasize that flame radiation is only one link in the chain of events which result in getting the heat in the fuel into the bath. Also, to treat the slag surface as if it were a slab of material having constant emissivity at all points may perhaps be misleading.

In answer to Dr. Chesters, it was the peak radiation of the flame which was measured, except of course at the end doors, where the radiation from the hot brickwork probably played a dominant rôle. The temperature of the latter would, to a large degree, be affected by the flame during the previous reversal, when it would of course be firing the other way. This is one of the big differences between the present work, and that done at Ymuiden, where the furnace was fired from one end only, which accounts for many of the apparent differences in the results.

In reply to Mr. Aitken, the steam pressure was measured at the burner. The burner consisted essentially of a convergent nozzle with the oil injected from a pipe a little upstream of it and concentric with it. It is possible that, as suggested, the stream was chilled by the oil, but this is unlikely, considering the short time the two were in contact before emerging.

In reply to Dr. Leckie, it would indeed have been preferable to have had some sort of heat sink available, provided that it was known how much heat should have been extracted. Since from preceding discussion it appears that the latter might depend on other characteristics of the flame besides its radiation, such a procedure might not necessarily make the results more applicable to melting-shop practice.

Dr. Leckie's remarks relating to getting high preheats by having high waste-gas temperatures are of course quite true. Only high preheats obtained 'fairly' are of value.

I cannot answer Dr. Baulk's question about the effect of the height of the slag surface.

In regard to superheating the atomizing stream, an experiment was tried out at Cardiff Works some years ago. A waste-heat boiler was isolated from the common steam main, and used to supply steam only to the burners of one furnace. This did not appear to result in any great change in fuel consumption or working rate.

Concerning Mr. Peters' comments, the measurement of the flame radiation with a hot background corresponds most nearly to the gross rate of heat transfer to the slag. It is agreed, however, that one would really like to obtain information about the effect of the radiation from the hot back-ground on the readings.

It is not considered that the measurement obtained when the flame has been turned off provides a satisfactory estimate, in view of the high rate of temperature decrease.

It is true that the radiation from the flame alone will be less than that from the flame plus the hot background, particularly at the outgoing end. It is, however, doubted whether Mr. Peters' explanation of the difference between the north and south ends is acceptable, since the emissivity of the back wall makes little difference to its radiation. This apparent paradox, explained elsewhere,* arises from the fact that the radiant energy emitted and reflected by the wall is about 100 times the conduction losses. It must also be taken into account that the furnace was of the reversing type.

Mr. Bacon's remarks about the desirability of having three or more levels for each of the variables are of course unexceptionable. It would be most satisfactory if estimates could be made of the non-linear components of variation.

Our knowledge of the principles of the regenerative system is not yet sufficient for an answer to be given to the question about the elapse of time necessary between successive experiments. Some indication can, however, be obtained from the time the checkers take to attain top heat after charging has finished, although of course there are complicating factors.

* J. H. Chesters and M. W. Thring, Spec. Rep. No. 37, p. 176: 1946, London, The Iron and Steel Institute.

The points at which the roof pyrometers were sighted divided the main roof into three. These instruments were not considered sufficiently reliable for any conclusions to be drawn from their readings.

One explanation of the benefits of high steam/oil ratios has already been advanced. It is difficult, however, to decide what is the optimum ratio for the refining period. Some of the best results at Cardiff in regard to both fuel consumption and working-rate have been obtained on a 100-ton furnace in which the flame hardly reached the first door during a large part of the refining period. This however may be an effect rather than a cause.

Mr. **Cude** (in reply) wrote: Mr. Evans asked me to calculate the flame length to be expected from a typical inside-mixing O.H. oil burner under specified conditions. Unfortunately, the flame-length relationship cannot be applied with certainty to this type of burner because our limited knowledge of the dynamic behaviour of mixtures of gas and liquid makes it impossible to calculate the jet momentum accurately. Some recent work by B.I.S.R.A. has supplied a little more information and using this I have prepared a curve (Fig. *A*) relating flame length to steam/oil ratio for a 1-in. dia. nozzle. This curve can be applied to burners of other capacities because, for a given steam/oil ratio, the flame length is proportional to the square root of the oil flowrate, provided that the steam velocity at the nozzle has reached the sonic limit.

It must be clearly understood that this curve applies only to high-pressure inside-mixing burners in which the steam has reached the sonic velocity in the discharge nozzle. This should be true for all inside-mixing burners normally requiring steam pressures greater than 50 lb./sq. in.

Dr. Chesters and Dr. Baulk both referred to steam superheating. An oil burner is a form of steam engine performing a mechanical process, and it is therefore essential to ensure that the steam arrives at the burner dry and with the minimum of pressure drop so as to obtain the maximum work from it. Well-lagged branch pipes of adequate size, free from unnecessary bends, and a burner designed to prevent undue heat loss to the cooling jacket, may well prove a better investment than an expensive superheater.

Mr. Pritchard's comments were of great interest as they show some of the practical difficulties which must be overcome in developing a satisfactory theory of oil-burner behaviour.

It is true that the rate of combustion of a droplet will depend on its size, but it also depends on the rate of mixing of air into the gases immediately surrounding the droplet. It must not be forgotten that oil requires thirteen times its own weight of air for complete combustion. If the droplet is large enough, then its rate of combustion may be dependent mainly on its size, but I suggest that under these conditions the flame will degenerate into a mere shower of burning droplets which will not be at all satisfactory. With smaller droplets the mixing process in the surrounding gas becomes the controlling factor; it is then that a homogeneous flame is obtained to which the equation which I formulated in my paper may be applied.

I have now applied my equation to a number of practical problems involving both light and heavy fuels, and ranging from small burners up to a typical forced-draught pressure-jet-boiler burner with a capacity of 1 ton/hr. of heavy fuel. In all cases the equation gave a satisfactory estimate of the flame length, and as far as I am aware, there is no equally good correlation between droplet size and flame length.

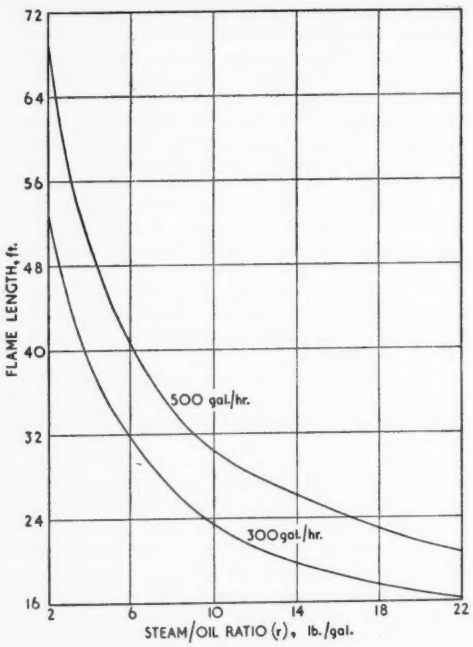

Fig. A—Flame length *vs.* steam/oil ratio for two flow-rates and limiting steam velocity

Similar arguments were successfully applied to pulverized-fuel flames by Davis.* I have also made some observations on pulverized-fuel flames which indicated that substantially all the fuel was burnt in the length given by the equation.

As Mr. Pritchard has pointed out, there are a number of additional factors to be taken into account when using the equation, and I have discussed these in a later paper.† The most important of these is the amount of excess air. The flame length is very sensitive to changes in the amount of excess air when this is less than 40%. Most oil-burning installations are not equipped to maintain close control of the air/fuel ratio, and I believe that the flame-shortening commonly observed as a furnace warms up is due entirely to the increased inflow of air with increasing thermal draught.

In a few cases a correction, analogous to a discharge coefficient applied to a nozzle, may be necessary to allow for internal losses in the burner. I was fortunate in choosing burners with negligible losses, but this may not be true of all burners. This correction can only be found by experience.

The inside-mixing O.H. furnace burner is a special case which may perhaps be dealt with by means of an empirical correction. As mentioned above, the flame-length equation as derived in this paper is not strictly applicable to these burners. Mr. Pritchard's observations, however, suggest that quite good results can be obtained if the equation coefficient is reduced to 1000. This is in quite good agreement with the laboratory tests carried out by B.I.S.R.A.

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* R. F. Davis, *Proc. Inst. Mech. Eng.*, 1937, vol. 137, pp. 11–53.

† A. L. Cude, *J. Iron Steel Inst.*, 1954, vol. 176, pp. 270–273.

Fig. A—Steel *A* annealed at 750° C., furnace-cooled × 700

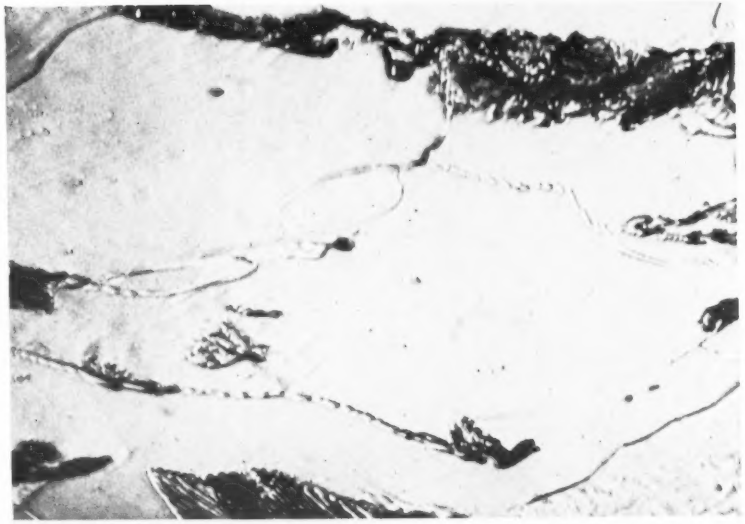

Fig. B—Deformed ferrite-grain steel *A* annealed showing breaks in carbide film × 1800

Fig. C—Brittle crack in Charpy specimen of steel *A* annealed × 1200

Discussion on the Paper—

TENSILE AND IMPACT PROPERTIES OF HIGH-PURITY IRON–CARBON AND IRON–CARBON–MANGANESE ALLOYS OF LOW CARBON CONTENT*

By N. P. Allen, W. P. Rees, B. E. Hopkins, and H. R. Tipler

Dr. **N. P. Allen** presented the paper.

Dr. **A. A. Wells** (B.W.R.A.): A number of strength data at various temperatures, together with Charpy V-notch transition curves, are given by Dr. Allen and his colleagues for the alloys under examination. In particular, it is evident that some alloys and treatments give very sharp transition temperatures, whereas at other times the transition is spread over a wide range. There seems to be no reason to deny the carbide film explanation given, but the issue is wider, and the span of the transition range depends mainly on the stress and strain characteristics for shear and cleavage respectively. Mr. Honeyman has suggested that it is generally accepted that sharp transitions depend upon high upper yield points. Having proposed this at an earlier date[1] I should be glad if this were accepted. The converse also appears to be true: materials with a large ratio of strain-hardening rate to yield point possess a wide transition range. These relationships could be clearly recognized in the N.P.L. results as in the results of Smith, Fostini, and Brick[2] for pure iron–carbon alloys, and Watanabe and Goda[3] for Japanese rimming steels. The reason for this behaviour is almost self-evident, if the shear strength of the material increases more than the cleavage strength with reduction of temperature. Such indications suggest how important it is that strong efforts should be made to measure cleavage strength by a direct method. Inference from notched-bar tests requires many assumptions as to the elastic or plastic behaviour of the material at the root of the notch before fracture occurs, and it is as yet impossible to check these assumptions adequately. Perhaps the well-known test of dropping a spherical specimen into a hot bath might be refined sufficiently for direct measurements of this nature.

Dr. **N. J. Petch** (Leeds University): Some recent measurements by Mr. Cracknell, Mr. Heslop, and myself have a bearing on the effect of quenching on the cleavage strength and the yield point.

The term σ_0 in my own paper is probably due to friction on the dislocation array by solute atoms and precipitates. Consequently, σ_0 should increase when the solute atom concentration is increased by nitriding or by quenching, and there should be a further increase on ageing, followed by a decrease on over-ageing when the precipitate becomes widely dispersed. Experimentally, we find that this is exactly what occurs. At room temperature, σ_0 obtained from the lower yield point is about 4 tons/sq. in. for annealed steel and increases to 10 tons/sq. in. for steels quenched from 680° C.

Mr. **A. J. K. Honeyman** (Steel Company of Wales): Is it possible to get these very low carbon steels with a fine grain ?

Mr. **W. Barr** (Colvilles Ltd.): In mentioning the high-manganese steels containing carbon contents of about 0·05%, Dr. Allen said he hoped that the steel industry would take note of and develop steels along these lines. Mr. Honeyman and I were among the first to point out the beneficial influence of manganese, and the steel industry is fully aware of the possibilities of steels with a high manganese/carbon ratio; indeed, structural steels are being made containing approximately 1·3% of manganese in which the carbon content has been reduced to the lowest practicable economic limit. We would, of course, like to reduce the carbon content further, even to the extent suggested by Dr. Allen, but unfortunately there is the important question of cost to be considered. Apart from the increase in furnace time involved in reducing the carbon to these very low limits, there is the price of the very low carbon ferro-manganese to be accounted for.

One of the most important points raised by this interesting paper of Dr. Allen and his collaborators is the effect of cooling rates. Therein lies the greatest possibility for improving the notch ductility of mild steels economically. The most likely way is in increasing cooling rates from the rolling temperatures and we are exploring that field at the moment.

CORRESPONDENCE

Mr. **P. Matton-Sjöberg** and Mr. **Y. Lindblom** (Domnarfvets Jernverk, Sweden) wrote: The question whether carbide films at the grain boundaries play a major rôle in the formation of brittle fracture in low-carbon steels has been the subject of investigation at Domnarfvets. The investigation was limited to one steel (*A*) of the following composition:

C, %	Si, %	Mn, %	P, %	S, %
0·09	0·28	1·42	0·016	0·025

The structure of this steel after annealing for 2 hr. at 750° C. and furnace cooling at a rate of 25° C./hr. is shown in Fig. *A*.

Micro-cracks in the carbide constituent were very frequent in notched-bar tests having this type of structure, when the test pieces were deformed either by impact or slow bending within the ductile range, provided that the deformation of ferrite grains was of sufficient magnitude. This is shown in Fig. *B*, the specimen being taken from the centre of a Charpy keyhole specimen deformed by impact. In this instance the carbide film has been broken up into small parts which have been displaced by the deformation of the ferrite. It will be observed, however, that this process does not appear to have caused any perceptible cracks in the ferrite.

Micro-cracks in the carbide were not observed when the test pieces were deformed in the brittle range. There was evidence that carbide films and pearlite areas offer a certain resistance to the propagation of a cleavage crack. There was also evidence that cleavage cracks in ferrite grains may be arrested by surrounding pearlite areas (*see* Fig. *C*).

In the normalized condition steel *A* does not show any, or at least shows very few, micro-cracks in pearlite areas. According to the theory that cracks in carbide start cleavage fractures in the surrounding ferrite, it would be expected that steel *A* in the annealed and furnace-cooled condition would show impact properties inferior to those in the normalized condition.

* *J. Iron Steel Inst.*, 1953, vol. 174, pp. 108–120.

The Charpy keyhole transition curves for the two structures are shown in Fig. *D*. The lower transition temperatures of the two curves are identical, the only difference between the curves being that the annealed steel with grain-boundary cementite has a slightly lower energy absorption in the ductile range.

The results show that the improvement of the impact properties with increasing manganese contents demonstrated by the authors cannot be due only to the disappearance of the carbide films. Probably, different heat-treatments and alloying with manganese do not only change the amount of carbide in the grain boundaries, but change the properties of the ferrite as well. All these different effects on the impact properties are superimposed on each other and the dominating effect may not be the same in steels of different heat-treatments and compositions. Some of the factors which appear to be just as significant as grain-boundary carbides when discussing impact properties of low-carbon steels are mentioned below:

Grain Size—When comparing the impact properties of samples from the same steel cooled with different rates from the austenitic region, the resulting matrix will contain bigger grains for lower cooling rates.

Formation of Martensite—When water-quenching from the austenitic range, martensite will be formed. The favourable effect on the strength of the structure attained by the presence of martensite is here superimposed on the favourable effect of decreased thickness of grain-boundary carbides.

Precipitation of Carbides and Nitrides from Supersaturated Ferrite—When quenching from the austenitic range it is possible to keep carbon in solid solution until the martensitic transformation takes place. In quenching from 700° C. where the solubility of carbon in ferrite is maximum, it is not possible to keep all this carbon in solid solution. Carbon probably precipitates in the ferrite grains in a similar way to during the ageing process. Such precipitates are known to have an unfavourable influence on the impact properties.

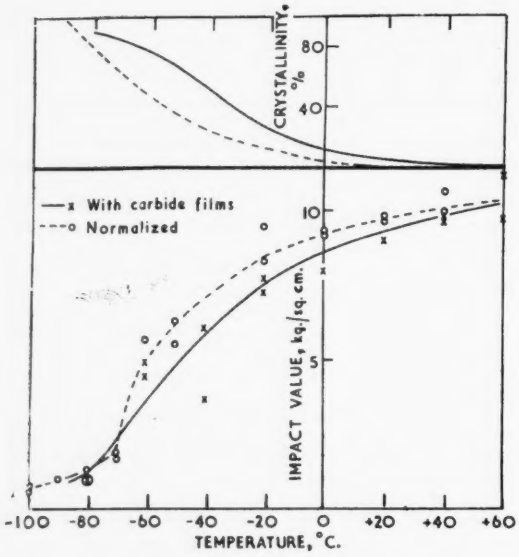

Fig. D—Charpy keyhole transition curves for steel *A* in the annealed and normalized conditions

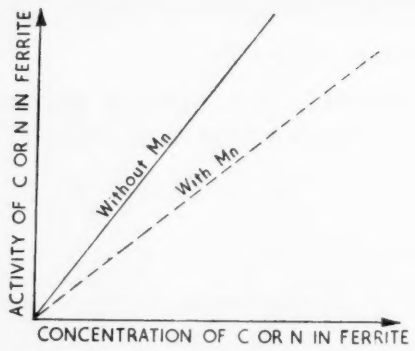

Fig. E—Influence of manganese on the carbon and nitrogen activity in ferrite

Effect of Manganese as an Alloying Element—Manganese in solid solution in ferrite tends to increase the strength of the ferrite as well as to decrease the thickness of the grain-boundary carbides.

Effect of Manganese on the Precipitation of Carbides and Nitrides in Ferrite—Manganese probably increases the solubility of carbon and nitrogen in ferrite. It is known that manganese has a higher affinity for carbon and nitrogen than iron. The presence of manganese tends to lower the activity of carbon and nitrogen as shown in Fig. *E*. If the carbon and nitrogen activities of carbides and nitrides are not lowered too much by the presence of manganese, the solubility of both carbon and nitrogen in ferrite will be increased and the tendency to ageing will diminish.

An interesting fact that has been shown by the authors is the connection between tensile strength and impact transition temperatures. When lower transition temperatures were obtained by heat-treatment or alloying with manganese, this was accompanied by an increase in tensile strength (if alloys with less than 0·02% of carbon be disregarded); this applies not only at room temperature but also when testing at — 196° C.

Since there is reason to believe that cracks in the carbide films had not occurred without considerable plastic deformation, it is difficult to understand why the tensile strength of steels with low transition temperatures is greater than for steels with higher transition temperatures. It is not adequate to attribute these differences in tensile strength at low temperatures merely to the prevention of carbide film formation, since available evidence indicates that cracks in the carbide films are not likely to appear before fracture in the specimens referred to. It would certainly appear that the differences in tensile strength at low temperatures observed by the authors cannot be fully explained without taking into consideration some of the factors mentioned above.

AUTHORS' REPLY

Mr. **Hopkins** (in reply): We should like to point out an error in Fig. 5, p. 114, of this paper. The label ' partly intergranular fractures ' should apply to curve *a* only, as is fairly clear from the text.

We wonder whether Dr. Wells is reading more into the paper than is justified. We do not think that any conclusion can be drawn about the rate of strain-hardening in the alloys dealt with because this was not determined. The paper presents no evidence that would enable the statement to be made that the rate of strain-hardening was low in those specimens that gave a sharp transition from tough to brittle fracture in impact, nor that the

ratio of rate of strain-hardening to yield point was low. High-purity iron, the material with the lowest yield point in the furnace-cooled condition, still gave a sharp transition in impact, and it was only when the carbon content was raised to give carbide films that a pronounced spread appeared in the lower part of the impact-value/temperature curve. We agree that there is need for work that will enable cleavage strengths to be determined at temperatures well above those giving brittle failure in plain tension.

Dr. Petch uses σ_0 to represent yield stress or cleavage strength, and whereas this leads to no confusion when the two are the same, *e.g.*, in his own results at − 196° C., σ_0 for cleavage at room temperature is obviously larger than the σ_0 of 4 tons/sq. in. for yielding. It appears to us at present to be somewhat curious that similar criteria should govern slip and cleavage, especially in so far as we are not convinced that cleavage cannot occur without some prior deformation. We do not therefore consider it obvious that our suggestion that carbon in solution raises the cleavage strength necessarily follows from the known fact that carbon in solution raises the critical shear stress or the yield stress.

In reply to Mr. Honeyman, high-purity alloys tend to be coarse-grained, but it seems likely that very low carbon steels made commercially would be easier to obtain in a finer-grained condition.

Mr. Barr's statement of the difficulties in producing very low carbon steels economically is very welcome, and there will no doubt be general satisfaction concerning his remarks about the efforts being made industrially to implement the knowledge that has now accumulated on the beneficial effects on impact transition temperature of faster rates of cooling.

We agree with Mr. Matton-Sjöberg and Mr. Lindblom that when a low-carbon material is deformed in the fully ductile condition the micro-cracks in the carbide do not spread into the ferrite. On the other hand, the ferrite deforms and flows into the micro-cracks in the carbide, as we have stated in the paper. It appears from Fig. *B* that the cracks in the carbide films shown occurred at a much earlier stage in the deformation than is represented by the photograph. In our specimens, the carbide cracks first appeared in quantity when the ferrite started becoming ductile under the stress conditions obtaining under the notch, that is, at the stage where the impact-value/temperature curve starts rising. It would appear from Fig. *C* that the cracks shown occurred in a region of the test piece that had not undergone very much deformation; some of the deformation has occurred by twinning but the Neumann band in the picture shows little or no sign of subsequent deformation by slip, so that the total deformation in this region could not have been large. The evidence in Figs. *B* and *C* therefore appears to support the statements made in the paper. We are pleased that Mr. Matton-Sjöberg and Mr. Lindblom agree that under certain conditions areas of carbide might be effective in hindering the progress of a crack in ferrite.

It is interesting that the transition temperature in the Charpy keyhole test is about the same for the annealed and normalized conditions in steel *A* in spite of the micro-cracks in the carbide being more in evidence in the annealed than in the normalized condition. The ease with which the carbide films crack will depend on their dimensions, and in steel *A* we should expect the films to be thin and therefore able to withstand more bending before they crack than coarse films. Any cracks formed will also be short, and the triaxial stresses would be expected to be correspondingly smaller. As, however, there was no difference in the transition temperature of the normalized and annealed specimens in spite of a greater tendency for the carbide films to crack in the annealed material, there must have been another factor causing the normalized material to be more brittle than would have been expected. We find this particularly interesting because we hope to publish shortly an account of work on iron–nitrogen alloys which shows that increasing the rate of cooling from the austenitic region reduces the brittle-fracture stress in tension and raises the transition temperature in impact at a nitrogen level that may be found in steels. Similar effects have been found in iron–phosphorus alloys. The reduction in brittle-fracture stress in these cases is due to a decrease in grain-boundary strength. It would appear significant that there are at least three regions, which we have marked *X*, *Y*, and *Z* in Fig. *C*, where the cracks run along the grain boundaries. It is thus suggested that this may well be the factor that has counteracted the effect arising from the difference in the tendency to form micro-cracks in the carbide in the annealed and normalized conditions. If this is correct, it is an illustration of the complexity of the effects obtained in a mild steel which can best be unravelled by working on high-purity materials. We have on a previous occasion[4] drawn attention to the occurrence of partly intergranular fractures in a mild-steel ship-plate, and Fig. *C* provides another example. In such cases it would appear that what is required to bring about a lowering of the transition temperature is an improvement in the grain-boundary strength, because the cleavage strength is probably normal.

The trend of the remarks by Mr. Matton-Sjöberg and Mr. Lindblom on the improvement in impact properties caused by the addition of manganese to iron–0·05% carbon alloys, as shown in Fig. 12 of our paper, suggests that we attribute this improvement to the disappearance of the carbide films. This is of course not so. We have merely explained the shape of the impact-value/temperature curves on the basis of the carbide films and the raising of transition temperature resulting from not having a sharp transition at the stage when the ferrite starts being ductile. We are well aware that the general positions of the curves on the temperature scale (more strictly, the positions of the first signs of ductility in the ferrite) are due to other factors such as grain size, manganese in solution in the ferrite, etc. This has been stated specifically in discussion of a paper by Mr. Matton-Sjöberg,[5] and we showed in an earlier paper[6] that manganese raises the cleavage strength of ferrite so that this effect in the iron–carbon–manganese alloys was not likely to be overlooked. Likewise we have not "attributed differences in tensile strength at low temperatures merely to the prevention of carbide-film formation"; in discussing the iron–carbon alloys, for example, we have rather emphasized the effect of retaining carbon in solution and of grain size differences.

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Joint Discussion on the Papers—

THE NOTCHED SLOW-BEND TEST AS A BRITTLE-FRACTURE TEST*

By J. E. de Graaf and J. H. van der Veen

THE FRACTURE OF ALPHA IRON† *By C. F. Tipper and E. O. Hall*

INTERGRANULAR BRITTLENESS IN IRON–OXYGEN ALLOYS‡

By W. P. Rees and B. E. Hopkins

THE CLEAVAGE STRENGTH OF POLYCRYSTALS§ *By N. J. Petch*

Dr. **J. H. van der Veen** (Royal Dutch Blast Furnaces and Steelworks), Dr. **E. O. Hall** (Sheffield University), Mr. **W. P. Rees** (National Physical Laboratory), and Dr. **N. J. Petch** (Leeds University) presented their papers.

Mr. **A. J. K. Honeyman** (Steel Company of Wales Ltd.): The urgent practical problem arising from brittle fracture in mild steel was the production of steel which would have considerably improved impact properties at low temperatures. Lowering the carbon content and increasing the manganese content provided the immediate answer, although no one knew exactly why it did so. Steelmakers can now produce straight carbon–manganese steels which have a remarkably low transition temperature, but they are too expensive for many applications, and the problem still remains of how to produce, at a reasonable cost, steel sufficiently notch-tough for particular purposes. In other words, how can we differentiate between the steel that is just good enough and that which is not quite good enough? This apparently simple question has posed a more difficult one: what properties exactly does a notched-bar test determine? The answer apparently is that it depends upon the bar, the notch, and the test conditions.

Professor de Graaf and Dr. van der Veen discuss this problem in their paper. As many people have not seen the paper describing the test, I hope Dr. van der Veen will give a brief description of it. How is a constant temperature maintained and how long does it take to carry out the test?

Are the two steels referred to in Fig. 9 of the same type? This is important, because in carrying out routine impact tests only steels of the same type are compared.

In regard to Table III of the paper by Dr. Tipper and Dr. Hall it is remarkable that such a small deformation should result in such a very great difference in the tensile strength of polycrystals.

Perhaps the two most interesting and puzzling points in the paper by Mr. Rees and Mr. Hopkins are the fact that no intergranular phase has been found to explain the phenomenon and, a point on which the authors do not comment, the coarse grain of the iron–oxygen alloys. Is this an inherent property of these very low carbon alloys? The question is of particular interest in view of Dr. Petch's paper, which shows a very close correlation between grain size and cleavage strength at − 188° C.

There can be nothing more gratifying to the physicist than to find his theoretical reasoning and calculations confirmed by his practical research or *vice versa*. I do not know which came first in this work of Dr. Petch, but he has most elegantly wedded the two in the present paper. The equation describing the relation between grain size and cleavage strength takes no account of precipitation effects, and Dr. Petch therefore warns us that it does not apply when such effects are present. But it is difficult to see how some at least of the grain sizes produced were not accompanied by precipitation effects. The cleavage strengths of the finer-grained steels are similar to those obtained by the N.P.L. workers with quenched steel.[1] Air-cooled steels have much lower cleavage strengths, and the differences are obviously not due solely to the difference in the grain sizes.

Fine grain sizes and precipitation effects are apparently related in some way, and I would suggest that those impurities which enable fine grain sizes to be obtained also cause precipitation effects. If this is so, the theoretical and practical equations are both correct, but the value of k depends on the initial temperature and the rate of cooling.

Dr. Petch's value for A agrees well with the average of the results obtained by Dr. Tipper.

There is a minor point of disagreement between Dr. Petch and the N.P.L. workers; the former states that an upper yield point is not obtained with grain sizes coarser than $l^{-\frac{1}{2}} = 5$, whereas the N.P.L. workers show an upper yield point with a grain size of $l^{-\frac{1}{2}} = 2$. This I think is confirmed by the abrupt notch-impact transition temperature, which is obtained only when there is an upper yield point. Is this discrepancy due to differences in heat-treatment?

Dr. **N. P. Allen** (National Physical Laboratory): The point about the paper by Professor de Graaf and Dr. van der Veen that interests me most is the change of emphasis over the past ten years. Ten years ago it was being argued whether the notched-bar value had any relation at all to the tendency of a mild steel to undergo brittle fracture under certain circumstances. Now the argument is concerned with the best way of determining the transition temperature, and whether one method gives it more accurately than another. That is a very significant change of attitude which shows the progress of the investigation.

The authors make the point that their notched-bend test shows less scatter than the **V**-notch impact test. Is this not due to the fact that their notched-bend test is done on a very much larger specimen, so that a better sample of the steel as a whole is taken in the one test,

* *J. Iron Steel Inst.*, 1953, vol. 173, Jan., pp. 19–30.
† *Ibid.*, 1953, vol. 175, Sept., pp. 9–15.
‡ *Ibid.*, 1952, vol. 172, Dec., pp. 403–409.
§ *Ibid.*, 1953, vol. 174, May, pp. 25–28.

as much as to the authors' explanation, that different degrees of account are taken of the energy absorbed in initiating the crack and in transmitting it?

I am glad that the authors are using their test to examine the variations between different heats of steel and different methods of making steel. In regard to susceptibility to brittle fracture, the ordinary mild steel varies unexpectedly widely from heat to heat; it is therefore necessary to find out how the variations can be controlled, so that the average quality of mild steel shall be equal to the best that is now accidentally produced.

The paper by Dr. Tipper and Dr. Hall illustrates the growing interest in single crystals of iron and their properties. A great deal of work has recently been done at the N.P.L. on single crystals. I agree entirely that there seems to be no essential connection between the production of Neumann lamellæ and the appearance of fracture. The Neumann lamellæ sometimes occur quite definitely long before the fracture occurs. Nevertheless, in our examinations of polycrystalline specimens at the N.P.L. there is very often an association of a crop of Neumann lamellæ with the path of the fracture, indicating that during fracture Neumann lamellæ are sometimes produced. They are sometimes produced in such fractures in spite of the fact that a considerable amount of cold work has taken place beforehand. The second crop of Neumann lamellæ seems to be due to the fact that when the fracture begins to form and propagate, there is immediately a change in the distribution and directions of stress. As twinning seems to depend very much on the direction of stress in the crystal, the alteration of stress direction may very well be the cause of the production of a crop of Neumann lamellæ.

Dr. Petch thinks that the dominant factor in brittle fracture is grain size; but his specimens contain enough carbon to saturate the ferrite. Consequently, precipitation of carbon may have taken place during his heat-treatments, and the effects of this precipitation must be taken into account, as well as those of the changes of grain size.

If there is a good theoretical reason for supposing that grain size should be dominant, the situation is very different from that which exists if there is no good theoretical reason. Dr. Petch has pointed out that the theory leads to the idea that the cleavage stress shall be proportional to the square root of the grain diameter. This was not found experimentally, and an arbitrary assumption has been introduced to account for the difference between experiment and theory. The suggestion that the atmosphere of dislocations round the slip plane produces this difference cannot be accurate, since that atmosphere consists of equal numbers of positive and negative dislocations, whose effects will cancel one another out. The suggestion that some kind of frictional resistance to the passage of dislocations causes the difference is much more promising. This resistance will probably be found to vary greatly in different cases; when the variables which influence it have been identified, opinions about the dominance of grain size will have to be modified a little.

Work on single crystals has afforded an opportunity of criticizing the general notions to some extent. It is supposed that the dislocations are held up at the boundary, producing a high stress locally which ruptures the next crystal. But with a single crystal there is no next crystal, so that single crystals ought not to undergo brittle fracture. But they do undergo brittle fracture. Theoretically, it might be thought that either the dislocations pass out at the surface and produce no stress, in which case the single crystal should be ductile, or there may be obstacles within the single crystal at which the dislocations may be held up, producing the same stresses as they would in the polycrystalline mass and causing cleavage to begin. In the second case, single crystals would be expected to be most brittle of all materials. In fact, single crystals of iron are sometimes brittle and sometimes ductile, according to their orientation relative to the stress. It is rather difficult to see how that fact is to be accommodated in the present theory.

Mr. **J. E. McLennan** (National Physical Laboratory): Work similar to that described by Dr. Tipper and Dr. Hall has been proceeding at the N.P.L. during the past two years. We have tested in tension over 50 crystals at temperatures ranging from 100° to − 253° C. The iron contained 0·003% of carbon with similar amounts of other impurities.

In many ways the results confirm those reported in this paper. We have studied the effect of two variables, temperature and orientation, on the behaviour of single crystals in simple tension. At the higher temperatures crystals of any orientation deform by slip to give 100% reduction in area. At low temperatures crystals of certain orientations cleave without prior deformation, others twin, and others of different orientation deform by slip. At lower temperatures still, all crystals become brittle. Discontinuous yields were obtained if the orientation and temperature of test were such that some ductility was exhibited. At temperatures down to − 196° C. the choice of slip system seems to depend both on orientation and on temperature. At − 196° C. cleavage on the (100) plane occurs without prior slip when the direction of stress is within 20–30° of the [100] direction. At certain orientations twinning precedes cleavage, and at others twinning precedes slip. Elsewhere, slip alone occurs. Crystals other than those deformed only by slip did not give 100% reduction in area. The results suggest that the critical resolved stress for twinning is about two-thirds the critical resolved stress for slip.

At − 253° C. all the crystals broke by cleavage, although in some instances twins were formed first. The resolved fracture stress normal to the cleavage plane was about 28 tons/sq. in. at − 196° C. and about 36 tons/sq. in. at − 253° C. These results suggest that the cleavage strength is strongly dependent on temperature and is not more or less constant. The critical shear stresses for slip and twinning both rise rapidly with fall in temperature, that for slip rising more rapidly.

Examination of the fractures suggested that twins which were not formed before cleavage could be obtained in two ways:

(i) By formation ahead of the propagating crack, since Neumann lamellæ matched in both halves of the fracture face
(ii) By shock waves as a result of fracture.

Mr. **A. M. Sage** (B.I.S.R.A.): The paper by Mr. Rees and Mr. Hopkins is a very valuable contribution to our knowledge of the properties of pure iron, which is now used in so much important research work.

There is a similarity between some of the results obtained in this work and those obtained from some recent work reported to the Institute on temper-brittleness; in both cases intergranular fracture is observed, but no intergranular phase is detected. Do the authors consider the mechanism of fracture in the iron–oxygen alloys to be similar to that suggested for temper-brittleness in steels? The most recent theory advanced for the latter suggests that it is due to the segregation of chromium or manganese atoms to the austenite grain boundaries and the subsequent segregation of carbon atoms to the ferrite boundaries. Might the intergranular

brittleness in the iron–oxygen alloys be due to the segregation of oxygen atoms, which associate with iron atoms at the grain boundaries in a pre-precipitation state ? If so, how and when does the oxygen grain-boundary segregation take place ? All the specimens mentioned in the paper were tested in the normalized condition, so that it would be expected that if the similarities with the temper-brittleness phenomenon held good this intergranular fracture would take place at the austenite boundaries. Are the authors able to say whether the intergranular form which they observed is confined to the original austenite boundaries ?

In connection with Fig. 2, the authors mention that above 0·003% of oxygen the proportion of intergranular failure in the brittle fractures increases. For a given alloy, were the areas of intergranular fracture found to predominate as the testing temperature decreased ? It would be particularly interesting to know whether the intergranular fracture predominated in the lower-temperature tests of the 0·011% oxygen alloy, as the transition curve for this alloy crosses the curve for the 0·007% oxygen alloy, and an increase in the oxygen content of the iron appears to produce a progressive increase in the curved portion at the lower-temperature end of the transition curve. If the crossing of these two curves and the change in shape of the curves with increasing oxygen content is not associated with differences in the fracture characteristics, what is the authors' explanation ?

Dr. **A. A. Wells** (British Welding Research Association): Professor de Graaf and Dr. van der Veen's new test for transition-temperature determination has certain advantages over the Charpy **V**-notch test, in that it uses a full plate thickness, giving ease of specimen manufacture and freedom from uncertainty about the spurious thickness effect which may be present in small specimens, and in that it uses the fracture-appearance criterion, thereby easing the comparison of inherently low- and high-energy materials having similar brittle-fracture characteristics. Some type of appearance criterion, such as transverse contraction, may be used on other tests. However, the authors' measurement of shear-lip depth is commendable for avoiding microscopic measurement. It would be useful if the authors could demonstrate the behaviour of the shear lip in their test, as, for instance, applied to a nickel steel and a spheroidal graphite iron, both of which show ductile and notch-brittle characteristics, but with widely differing energy absorptions.

Dr. Tipper and Dr. Hall demonstrate the difficulties in conducting single-crystal tests, but these tests are very informative. In view of the complexity of shear behaviour, it would have been better if the cleavage mode had been simple, with cleavage always on one plane and adherence to Sohncke's law. Could the authors explain whether Sohncke's law had to be abandoned for α-iron, or whether the discrepancy was attributed to experimental error ? It was interesting to see that the breaking loads on the authors' specimens were much lower where the cleavage planes were nearly transverse to the axis of pull. This could be regarded as supporting evidence for Dr. Tipper's explanation, on the basis of orientation, of her earlier observation that the fracture faces for fully propagating notch-brittle fractures showed the abundant presence of sheared as well as cloven crystals.

In detecting the presence of intergranular fractures with high-oxygen irons, one hopes that Mr. Rees and Mr. Hopkins are not foretelling a gloomy future for those concerned with steel structures. Could the authors indicate the practical possibilities of this statement ? Is it possible that, for instance, under the right conditions, mainly intergranular fractures might propagate like cleavage fractures, or should the intergranular separations be regarded only as another way of initiation ? In the light of experience with commercial low-carbon steels, the former possibility would seem to be doubtful.

Dr. Petch has done well to show that, when the austenite grain size has previously been standardized, the cleavage strength and yield of steels can be so strongly dependent on ferritic grain size. This, in itself, is probably more important than any of the explanations which can now be put forward. The author appears to have abandoned the Griffith crack explanation when it was discovered that the single crystals still possessed a finite cleavage strength σ_0. However, it is difficult to see why the flow mechanism should not be taken to be the cleavage facet on an individual crystal, bearing in mind that it need not exist as a true Griffith crack, until the necessary cleavage stress σ_0 had first been applied. Further application of load would then be required to supply sufficient elastic energy to make the crack run. Such a mechanism could explain the existence of σ_0, but Dr. Petch will probably have already rejected it. His reasons for doing so would be interesting.

Dr. **P. L. Pratt** (Birmingham University): Dr. Petch's elegant treatment in his paper shows that the stress concentration due to dislocations blocked at grain boundaries can account for the observed dependence of cleavage strength on grain size. In the course of this treatment he seeks to identify Griffith cracks with blocked glide planes of length equal to the semi-diameter of the grains; this implies an effective crack length varying from the order of centimetres for a single crystal to about 10^{-2} mm. for material with 8000 grains/sq. mm.

However, by introducing a plastic work factor into the Griffith formula, Orowan has shown that the limiting length for stable cracks in fine-grained iron is about 1 mm., and this implies that the cracks must extend across about 100 grains before they can result in brittle failure. On the other hand, Hall has shown that, for single crystals, Orowan's estimate of the plastic work factor is several times too great, and thus the critical crack length for coarse-grained material should be of the order of 10^{-3} mm.

In other words, very short Griffith cracks should become unstable in single crystals, leading to brittle fracture, whereas relatively long cracks are required in fine-grained material. This is in direct contrast to Dr. Petch's identification of Griffith cracks with the semi-diameter of the grains themselves, and some reconciliation is required between these theoretical crack lengths and the experimental results.

It is very reasonably suggested that " actual cracks of the Griffith form in a metal would close up in the absence of external stress "; but suitable external stresses are present in specimens pulled in tension to the point of fracture, and small cleavage cracks, not long enough to be unstable in the Griffith sense, do develop under certain conditions during deformation before fracture. There is direct experimental evidence for this, and in many of the published micrographs of sections normal to fracture faces subsidiary cracks can be seen at some distance from the major fracture surface. In this paper greatest weight is given to those results where the correction for plastic deformation is zero or small, and this gives the clue to an understanding of the results in terms of the theoretical Griffith crack lengths. For coarse-grained material this crack length is smaller than the grain size, and the stress concentration due to the number of blocked dislocations determined by the grain size can nucleate a crack of theoretical length. This crack can then accelerate to such a speed in the same grain that it will propagate to failure. From Fig. 3 it can be seen that the limiting

grain size is given by $l^{-\frac{1}{2}} \simeq 4$ mm., and this is equivalent to a crack of length 10^{-1}–10^{-2} mm. This figure should be compared with a theoretical crack length for this intermediate grain size less than 1 mm., the value for a single crystal, but not as small as 10^{-3} mm. It seems that $l^{-\frac{1}{2}} = 4$ is that grain size at which the stable Griffith crack, on average, just crosses the grain from boundary to boundary, and so is unable to become a rapidly moving crack. For finer-grained material than this the crack must be made to extend across more than one grain before brittle fracture can develop, and the experimental facts bear out this prediction. For grain sizes smaller than $l^{-\frac{1}{2}} = 4$ mm., the material deforms plastically, by an amount proportional to the grain size up to a limit of 35% reduction in area, and these are just the conditions required to open up and join together a number of small Griffith cracks, until they can become one crack large enough to promote brittle fracture.

Some very recent work has been done in the U.S.A. by Low on brittle fracture in iron, of which I have been told by Professor Cottrell. It shows that (taking, for example, Fig. 3 in Dr. Petch's paper) grain sizes below $l^{-\frac{1}{2}} = 3$ do not deform before failure, but give a completely brittle fracture, whereas above this grain size the material is ductile.

Figure 3 shows a suspicion that the curves for σ_c and $\sigma_{l.y.p.}$ are crossing over, but σ_c does not fall to zero at the origin, as Low's work suggests. Low has calculated from the shape of his curves the value for the Orowan work factor; and for the case of σ_c falling to zero, where the oxygen content is high enough to give intergranular failure, this value is that for the surface energy and no more; in de-oxidized steels, however, the value of this work factor is about 100 times larger, showing that work of plastic deformation is being done in the case of cleavage failure.

Mr. Rees and Mr. Hopkins suggest that the addition of manganese renders oxygen less harmful as an embrittling agent in iron, eliminating intergranular failure. Can it be that service failures in the past which, in the absence of manganese, were by implication due to oxygen, were in fact of the intergranular rather than the cleavage type ?

Mr. **G. Murray Boyd** (Lloyd's Register of Shipping): The paper by Professor de Graaf and Dr. van der Veen is important, timely, and useful. The problem of the control of notch brittleness in mild steel from the practical engineer's point of view has produced many different types of test, all intended to discriminate between suitable and unsuitable steels from this viewpoint. The multiplicity of such tests has set a serious problem for those in whose interest it is to select the best. This selection is in itself a problem comparable in magnitude and difficulty with that of elucidating the phenomenon itself.

From the user's point of view, any such test must stand or fall on its ability to comply with three main conditions:

(i) It must correlate with service performance
(ii) Its indications must be as free as possible from personal errors of judgment
(iii) It must be practical and economical to apply.

From the paper, it is evident that conditions (ii) and (iii) are fairly well met by the proposed test, but little evidence is given on condition (i). The reason for this is, of course, that such correlation is excessively difficult to establish, and has not in fact been definitely established for any known test for this property, not even for the Charpy **V**-notch test. It is true that the American Bureau of Standards investigations produced a great deal of evidence upon the correlation, which was quite good, between the Charpy **V**-notch 15-ft.lb. transition temperature and the experience with welded-ship fractures. This evidence, however, is not entirely satisfactory, for two reasons, one of which is given in the present paper.

The first of these is that the criterion chosen is very difficult to establish definitely with a reasonably small number of specimens. This uncertainty is shown in the paper for an energy level of 4 kg. m./sq. cm., *i.e.*, 23 ft.lb., and the uncertainty would undoubtedly be greater at 15 ft.lb. The second difficulty is that there are strong indications that no criterion based solely on energy as shown by the Charpy **V**-notch test does in fact correlate with service performance for all structural steels. It appears that a higher energy level should be demanded for fully killed steels than for semi-killed or rimming steels. This point is clearly brought out in a recent paper by Puzak *et al.*[2] The point is also implicit in Fig. 10 of the paper, which shows that criterion (*b*) correlates better than (*a*) with the notched slow-bend transition. This is, however, not unnatural, since the latter is a fracture-appearance criterion.

In view of the inherent difficulty of direct correlation with service performance, one may fall back on the indirect method of seeking criteria which agree between themselves, irrespective of the geometry of the test specimens. This is found to be the case for fracture-appearance criteria, in agreement with the present paper, and this is a strong argument in favour of the proposed test. Equal claims can, however, be made for several other tests, including the Tipper test, the Robertson test, the Navy tear test, the Pellini test, and several others. The percentage fibrous (or crystalline) in the Charpy **V**-notch test is also in the same category.

The chief drawback to criteria based on character of fracture is the difficulty in measuring it. This entails distinguishing by eye between two kinds of fracture texture, and this necessarily entails the human element. This difficulty, however, is not unsurmountable, since it occurs and has been overcome in many other fields, such as matching of colours and textiles, etc.

The explanation given in a paper of mine,[3] referred to by Dr. Tipper and Dr. Hall, is rather more than tentative. In considering the surface markings on fracture faces, it is important to distinguish between the chevron pattern, which is a feature of fractures in plates of uniform thickness, and the striations which appear on the cleavage faces of individual crystals. It is also important to distinguish between the markings which are traces of the actual fracture fronts and those which are the tracks left behind by the fronts in their advance. The latter are perpendicular to the former. All four of these separate concepts are, to my mind, confused in the discussion given in the paper, without detriment, however, to the conclusion that these surface markings are unrelated to the crystal structure, and that they are associated with energy absorption which is additional to that of simple cleavage.

The distinction between ' front ' markings and ' track ' markings is well illustrated by Fig. 7*a*, in which a leaflike pattern is shown. The front markings are the edges of the leaves, which are of curved and scalloped form. The track markings, on the other hand, are the veins of the leaves. The chevron markings on plate fractures are track marks, which are orthogonal (*i.e.*, perpendicular) to the roughly parabolic front which is characteristic of fractures in wide plates. These chevrons are on an entirely different scale from the striations on individual crystal faces, but there is probably some similarity in their causes or character. The track markings on crystals are probably due to steps, or differences in level, as shown in section in Fig. 6*b*. Chevron markings are sometimes

also found in the form of similar steps, though on a much larger scale, but sometimes they are merely gross irregularities in the surface, which tend to lie in a direction perpendicular to that of the advancing front. Similar irregularities are sometimes observed radiating from the centres of cup-and-cone fractures, particularly in alloy and heat-treated steels.

Changes in the directions of track markings do not necessarily denote changes in velocity, but the presence of front markings probably denotes such changes, or even arrests, in the progress of the fracture front.

Figure 7 is particularly interesting, and especially the zigzag line running diagonally from the inclusion or hole. It can be seen that the main markings, which are probably of the track variety, run perpendicularly into the legs of the zigzag, which are probably front marks. It is also interesting to note that the track marks tend to finish perpendicular to the specimen boundary (lower edge) and to the circumference of the hole. This is entirely consistent with the explanation given in my paper,[3] but it does not necessarily denote a slowing-up of the front, as suggested in the present paper.

The relationship between the track markings and energy absorption is well shown in Fig. 6*b*, where the distortion associated with the steps is quite evident.

My remarks on Dr. Petch's paper will be confined to the interpretation of the facts, and in particular to the theory. One is tempted to inquire how the results would be affected by variations in the diameters of the specimens. The breaking stress would probably be affected by the ratio of specimen diameter to grain size, particularly when the latter is large in relation to the former. A non-metallurgist may also inquire whether the various heat-treatments did anything else besides altering the grain size.

The concept of brittle strength, or cleavage strength, is very difficult to grasp when examined critically, particularly when it is realized that it can only be measured at very low temperatures. Although this concept has had a considerable vogue for many years, it seems desirable that, like all other fundamental concepts connected with fracture, this should be submitted to critical scrutiny. This applies equally to the concept of stress itself, which has in recent years been severely stretched beyond its original simple meaning, *i.e.*, load divided by cross-sectional area. This scrutiny of the meaning of stress is especially necessary where plastic deformation and fracture are involved. The engineering concept of stress, moreover, is related to hypothetically homogeneous materials, and cannot properly be applied when the grain structure has to be considered.

Dislocation theory, which has also been invoked in the paper, has grown enormously since it was originally introduced as a brilliantly successful device to explain certain discrepancies between observation and theory in relation to yielding. As an engineer, I regard dislocation theory with some scepticism, on the grounds that it appears to explain too much. However, I have tried to form a working hypothesis. Cleavage appears to be a process by which a crystal may suddenly divide into two or more parts, the division taking place sensibly on a plane having a certain definite orientation in respect to the atomic lattice. This process seems to be akin to a chain reaction by which the attractions between the atoms are successively overcome. This chain reaction must start either in the interior or at a boundary of the crystal, by the severance of one or more atomic bonds, the energy released by which ruptures the neighbouring bonds, and so on. In some materials (*e.g.*, coal) the cleavage process can be produced by a light tap at the right place, even in the absence of a tensile stress. In metals, however, it seems that even at very low temperatures some tensile stress is necessary for cleavage to occur, but it appears that the stress does not so much cause cleavage as render it more probable. The stress which renders cleavage a practical certainty might properly be called the ' cleavage strength,' but this must remain an abstract concept, since it must vary from crystal to crystal, according to their orientation, structure, previous strain history, etc.

By an extension of this conception it appears reasonable to define the cleavage strength of a polycrystalline aggregate as that stress at which the ' chain reaction ' will spread right through the aggregate. This means that the energy released by the cleavage of an initial crystal, or group of crystals, is sufficient to break down the neighbouring crystals.

In an actual specimen, however, the position is severely complicated by the fact that each crystal has alternative modes of breakdown, such as plastic deformation, which may enable it to accommodate itself to its changing environment without necessarily cleaving. The object in cooling the specimens drastically is to eliminate these alternatives, but this is an entirely artificial and unrealistic process if one is concerned with explaining the occurrence of cleavage at higher temperatures. To apply the results of such low-temperature experiments to more realistic conditions, it is necessary to make the important and unverifiable assumption that the cleavage strength so determined does not vary with temperature. The results might be called ' comparative,' but this tacitly assumes that any dependence on temperature is the same for all materials and grain sizes.

What has been said about temperature dependence might also be said about the dependence of cleavage strength on strain. This aspect has been covered in the paper by applying a correction based on experiment, but these experiments are also open to scrutiny on similar lines.

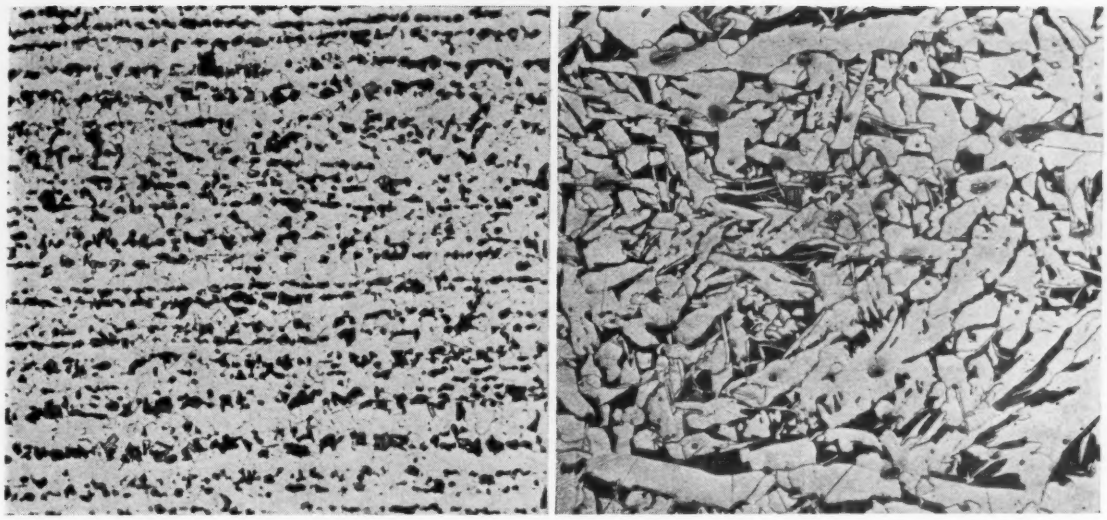
Mr. **T. S. Robertson** (Naval Construction Research Establishment): Dr. Petch presents new information on the cleavage and yield strengths of steel and iron at low temperature, which, together with the simple relationships with grain size, should lead to an eventual understanding of the mechanism of initiation of fracture.

Some recent work on the effect of grain size on the propagation of running cracks reveals the gap which has yet to be covered before this work can be applied to the catastrophic failure of structures.

Following up a suggestion by Dr. Hume-Rothery that crack-arresting tests should be made on steels with really large grains to determine whether the crack changed from intracrystalline to intercrystalline, two 1½-in. mild-steel plates were selected. One was a grain-controlled mild steel, normalized (C, 0·16%; Si, 0·150%; Mn, 1·07%), and the other a commercial mild steel, fairly coarse-grained as-rolled (C, 0·16%; Si, 0·045%; Mn, 0·6%). Portions of the plates were heat-treated through the courtesy of Dr. Sykes at the Brown-Firth Research Laboratories, where each was soaked for 2 hr. at 1290° C. Charpy, Izod, and stress/arrest-temperature curves were obtained for both the steels, in prime condition as-received and after soaking.

Figures *A* (i) and (ii) show the structure of the grain-controlled steel as-received and after soaking, the ferritic grain sizes being $l^{-\frac{1}{2}} = 6{\cdot}8$ and $5{\cdot}2$ per mm., respectively. For the crack tests the plates were machined down to 1-in. thickness to remove the decarburized layer. Figure *B* shows graphs of the test results. All cleavage fractures were intracrystalline.

The Charpy and Izod temperatures for 15 ft.lb. energy show only a moderate rise of 15° C. after this drastic



(i) (ii)

Fig. A—Structure of grain-controlled mild steel (i) as received, (ii) after soaking for 2 hr. at 1290° C. × 100

treatment. The crack tests, however, show a rise of 35° C. in the crack-running temperature, which is more in keeping with normal expectations of embrittlement.

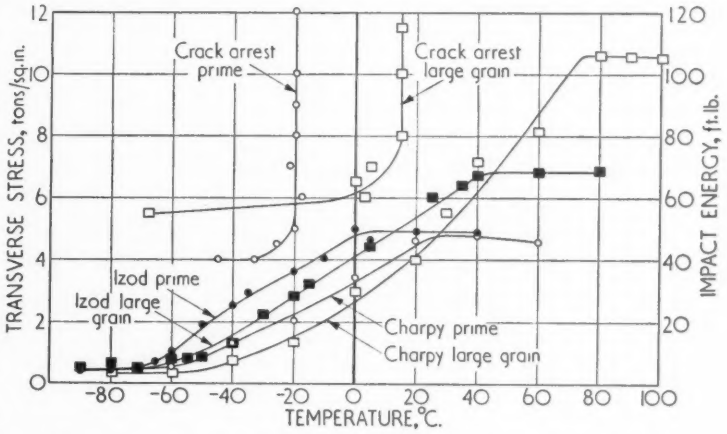
The lower part of a crack-arrest graph gives a measure of the strength to resist a running crack, and the apparent anomaly arises that the fine-grained material will run cracks at — 30° C. when the transverse stress is 4½ tons/sq. in., whilst the large-grained material will arrest a crack at 5½ tons/sq. in. at that temperature. To explain this anomaly it is suggested that the arrest of running cracks is allied to the yielding of the material, whilst their continuance depends upon the degree of tri-axiality of stress ahead of the crack. It is submitted that a higher transverse stress in the plate may be required to achieve the necessary degree of tri-axiality in the large-grained material with yield at only 16·3 tons/sq. in. The much-enhanced energy for Charpy and Izod upper values in the large-grained material is significant and can only be due to increased ductility.

Figures *C* (i) and (ii) show the structure of the commercial mild steel as-received and as-soaked to the same scale as Fig. *A*. The ferritic grain size as-soaked is $l^{-\frac{1}{2}} = 4 \cdot 2$ per mm. and as-received 5·1 per mm. Figure *D* shows the relevant graphs. Here the changes in Izod and Charpy transition temperatures at 15 ft./lb. are small. The material in the prime condition would be judged to be slightly worse than after soaking. The soaked material again shows higher upper energy values.

The crack tests show little change in upper arrest temperature, but the change follows the indications of the impact tests and all cracks are intracrystalline. The strength to arrest cracks again follows the lower yield, the larger grain size, and higher energy absorption of the soaked material. For this plate the lower knee of the Charpy graph, corresponding with 100% cleavage, agrees in temperature with the upper arrest in the crack tests, but for the soaked grain-controlled plate it is found at a much lower temperature than the upper arrest. The Izod tests on both qualities of plate show 100% cleavage at 50–60° C. below the upper arrest temperature. This degree of correlation in the Izod test is established in a recent paper.[4]

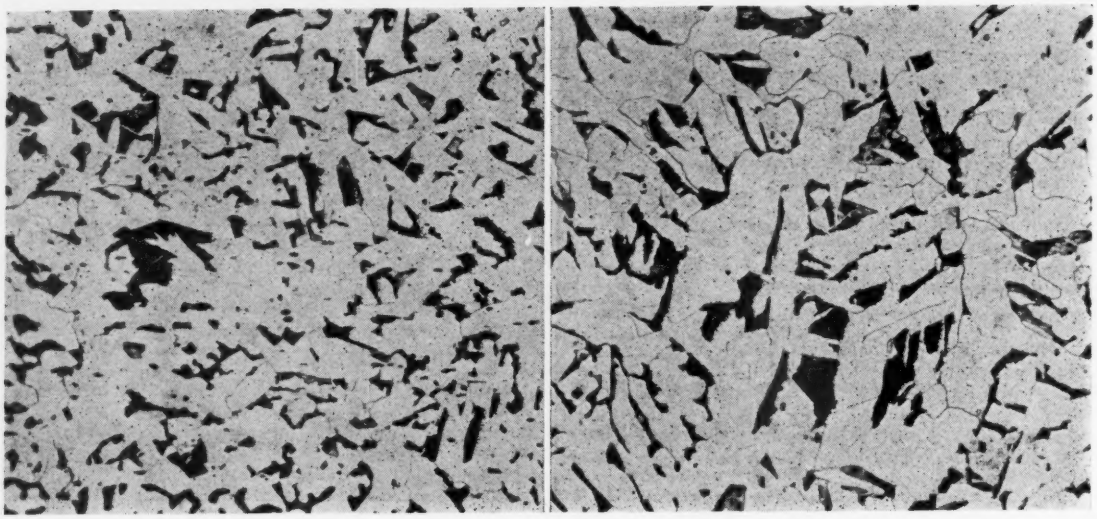
Mr. **G. Burns** (Admiralty Materials Laboratory): Presumably with a view to abbreviating his paper, Dr. Petch has omitted details of the heat-treatments used to obtain the range of ferrite grain sizes used in his work, but in view of the difficulties of developing coarse ferrite grain sizes from fine-grained austenite and *vice versa*, it seems a reasonable assumption that the heat-treatments would involve developing a range of austenite grain sizes in his samples. Has he given any attention to a possible correlation of the austenite grain size with brittle strength ?

In some work at the Admiralty Materials Laboratory,



○ ● As received. Yield stress 19·2 tons/sq. in., U.T.S. 30·9 tons/sq. in. Ratio 0·62
□ ■ As annealed. Yield stress 16·3 tons/sq. in., U.T.S. 29·9 tons/sq. in. Ratio 0·54

Fig. B—Effect of grain size on crack-arresting and impact transition temperatures for grain-controlled mild steel



(i) (ii)

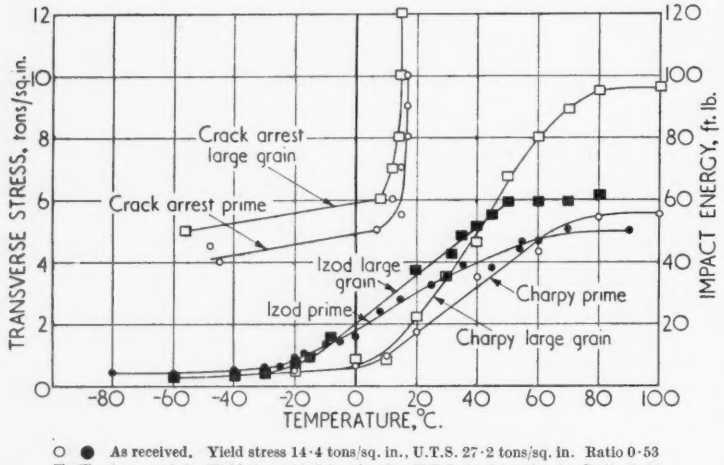
Fig. C—Structure of commercial mild steel (i) as received, (ii) after soaking for 2 hr. at 1290° C. × 100

in which the effect of microstructure on transition temperature in a notched-bend test was examined, it was found that the grain size of the austenite from which the final structure is formed is a significant factor; a coarse austenite grain size always led to a high transition temperature. In general, a coarse austenite grain size results in a coarse ferrite grain size, but when coarse-grained and fine-grained austenites were cooled at different rates so as to give substantially the same ferrite grain size, the material of coarse initial austenite grain size still had the higher transition temperature. Whilst transition temperature is not a measure of brittle strength, it is likely that there is a loose relationship between these factors.

Thus it is possible that some of the effect attributed to ferrite grain size may, in fact, be attributable to the grain size of the austenite from which the ferrite was formed.

The thesis which Dr. Petch puts forward to account for the relationship he finds between brittle strength and ferrite grain size seems to imply, although this is not specifically stated, an expectation that each grain in the path of the fracture will be severed by a single cleavage crack in any one of the cleavage directions.

An extensive metallographic study of the fracture paths in some samples of mild steel broken in a brittle manner showed that in many (possibly most) cases grains were not severed by a single cleavage crack extending right across the grain; there were two or more cleavage cracks in the same direction but in different planes, each traversing a part of the grain, and joined, where they overlapped, by short lengths of shear fracture; Fig. 6*b* of the paper by Dr. Tipper and Dr. Hall shows a fracture of this type. This seems to suggest that in each grain there may be a varying number of sources from which cleavage in one direction may occur, rather than one unique source for the direction, as seems to be implied in Dr. Petch's discussion.



○ ● As received. Yield stress 14·4 tons/sq. in., U.T.S. 27·2 tons/sq. in. Ratio 0·53
□ ■ As annealed. Yield stress 11·5 tons/sq. in., U.T.S. 26·2 tons/sq. in. Ratio 0·44

Fig. D—Effect of grain size on crack-arresting and impact transition temperatures for commercial mild steel

It would be interesting to know whether Dr. Petch's thesis about the cause of the relationship between grain size and brittle strength will hold good in the event that the size of the cleavage fractures in a grain may be variable.

In the metallographic survey of the paths of brittle fractures mentioned, it was found possible in some instances to develop patterns of etch pits in grains traversed by the fractures and, in every case where the pits were developed clearly enough to be sure of the grain orientation, the fracture planes were parallel to the cube faces of the etch pits.

In a note at the bottom of Table III of their paper, Dr. Tipper and Dr. Hall mentioned that audible twinning occurred in some of their test pieces. During slow notched-bend tests of some specimens at the Admiralty Materials Laboratory, intermittent clicks were heard while

the specimens were still in the elastic range; each click was accompanied by a very small jog in the autographic stress/strain wave which was being taken. Unfortunately, none of these tests was stopped before fracture, and a later attempt to find further samples showing the phenomenon was unsuccessful. However, an examination of several test pieces in which clicks had occurred and a comparison of them with similar specimens not giving clicks showed a difference. In those in which audible clicks had occurred no twinning was observed, but there were a number of more or less isolated fractured grains at some distance from the fracture path. In the specimens in which there had been no clicking, no fractured grains were found far away from the main fracture path.

Dr. **B. C. Woodfine** (B.I.S.R.A.): In regard to Dr. Petch's paper, it would seem at first sight to be very unlikely that three materials of such different composition as ingot iron, spectrographic iron, and mild steel would obey exactly the same cleavage-strength/grain-size equation, particularly since the specimens will contain different amounts of a second phase, depending on the heat-treatment used to obtain the final grain size. If the cleavage strength of iron is related to the grain size by the simple relationship suggested by Dr. Petch and is independent of carbon content from 0·036% to 0·155%, manganese content from 0·005% to 0·59%, and phosphorus content from 0·005% to 0·028% (to take only three examples), much of the work now being carried out on the effect of alloying elements on ferrite is apparently unnecessary; this position is hardly borne out by the results being obtained.[1, 5, 6] Varying the rate of cooling from the austenite region will not only produce different grain sizes but will also give different amounts of carbon in solution with corresponding variations in that precipitated as carbide; the distribution of carbide will also be altered and, with the slow cooling rates used to obtain the large grain sizes, grain-boundary films of carbide must occur. As shown in the paper by Mr. Rees and Mr. Hopkins, carbide films at the boundaries can initiate cleavage failure, so that under these conditions a deviation from any cleavage-strength/grain-size relationship would be expected.

In applying a strain correction taken from the work of other investigators to his fracture-stress results, Dr. Petch has assumed that the variation of cleavage strength with strain is independent of composition and grain size, without giving a justification for these assumptions. The work of McAdam, Geil, and Mebs[7] was concerned with an ingot iron and a mild steel different in composition from those used by Dr. Petch and was carried out at only one grain size. It would have been much more satisfactory if the dependence of cleavage strain on strain had been experimentally determined by Dr. Petch for the materials he used in the investigation, particularly since some of the corrections were apparently up to 30% or more of the measured value.

Dr. Petch claims that the lines showing the dependence of cleavage strength σ_c and lower yield point $\sigma_{l.y.p.}$ on grain size intersect at $l^{-\frac{1}{2}} = 0$, thus giving the same value of σ_0 in each equation. In Fig. 3 there is some indication that the lines actually intersect at a point above $l^{-\frac{1}{2}} = 0$, and if, in Fig. 1, the σ_c line is fitted to all the points, including those above $l^{-\frac{1}{2}} = 5$, the σ_c and $\sigma_{l.y.p.}$ lines will certainly intersect above $l^{-\frac{1}{2}} = 0$. It is clear from Fig. 3 that this must in fact be the case if the reduction in area has been measured accurately. No reduction in area means that $\sigma_{l.y.p.} \geqslant \sigma_c$, which according to Dr. Petch is only satisfied at $l^{-\frac{1}{2}} = 0$, so that above this point it should be possible to measure or observe some plastic deformation. However, the reduction in area for the ingot iron and mild steel is shown to be zero at $l^{-\frac{1}{2}} = 2{\cdot}5$ and $l^{-\frac{1}{2}} = 4$, respectively, so that clearly the σ_c and $\sigma_{l.y.p.}$ curves must intersect for ingot iron at $l^{-\frac{1}{2}} = 2{\cdot}5$ and for mild steel at $l^{-\frac{1}{2}} = 4$. Under these conditions, one of the claims made by Dr. Petch is wrong: either $\sigma_{l.y.p.}$, or most probably σ_c, is not identical for both materials.

The theory as presented in the paper neglects any interaction of dislocations with either solute atoms or precipitated particles, although Dr. Petch has indicated that he now considers that the σ_0 term in the equations will arise from this effect. If this is so, it is difficult to see how three materials with different carbon, alloy, and impurity contents and containing different amounts of a second phase can possibly have the same σ_0 term, as Fig. 1 apparently shows.

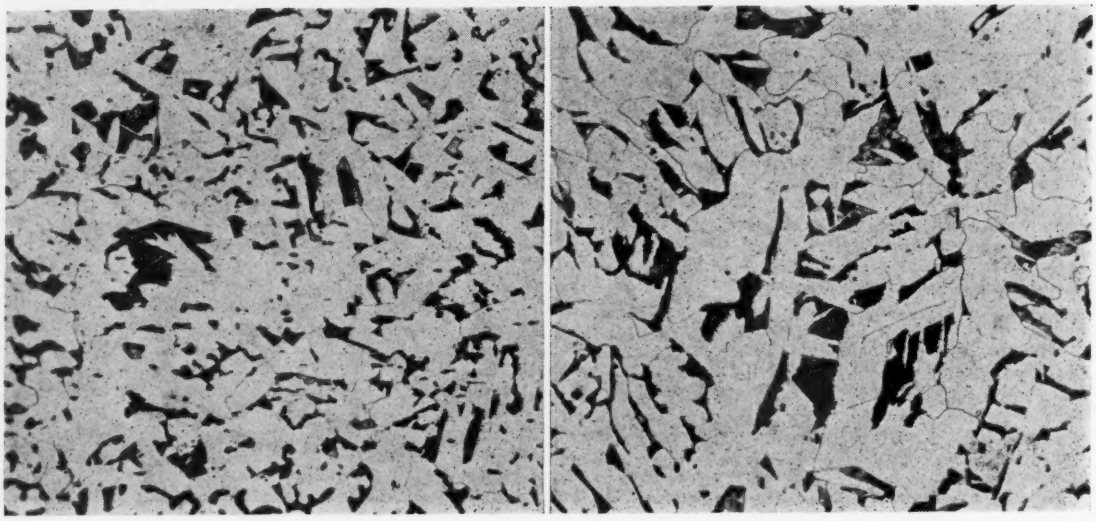
However, there are two more fundamental respects in which the theory is unsatisfactory; these are the effect of tri-axial stresses on cleavage fracture and the temperature dependence of the yield stress and cleavage strength. Dr. Petch states that cleavage, like the lower yield point, is concerned with stress concentrations produced by blocked glide planes, but he has apparently overlooked the fact that if cleavage is dependent on the presence of shear stresses, the cleavage strength should be raised by tri-axial stresses in the same way as the yield stress. If this is the case, the Ludwik–Orowan theory of notch brittleness requires reconsideration, and it is difficult to see how the phenomenon of notch brittleness could be explained. There is no reliable evidence to show that the cleavage strength is raised by tri-axial stresses, and the effect of increasing tri-axiality on the ductile–brittle transition indicates that yield and cleavage are not affected in the same way. Similarly, from the results of Eldin and Collins[8] the effect of decreasing temperature on yield and cleavage is far from identical, indicating that the controlling mechanism of each process is not the same, as Dr. Petch's theory would indicate.

Although Dr. Petch states that some results for single crystals are included in Fig. 1 he does not indicate how his theory can explain the cleavage fracture of these crystals. Clearly, any stress concentration developed by slip must occur outside the surface of the crystal and cannot lead to subsequent cleavage fracture.

In Fig. 1 $l^{-\frac{1}{2}}$ is proportional to the average grain diameter, but if stress concentrations produced by blocking of dislocations are to lead to failure, then surely —since in the theory Dr. Petch has considered the source at the centre of the grain to give the greatest stress concentration—in applying the theory he should use not the average grain diameter but the maximum grain diameter found in the specimen. The largest grain is much more likely to initiate fracture than the smallest grain. Has Dr. Petch considered his results from this point of view ?

How is the conclusion reached by Dr. Petch " that subtle effects of composition are possible owing to the segregation of solute atoms to (the grain-boundary) region " correlated with Fig. 1, where a complete independence of composition and heat-treatment is shown ?

The absence of a grain-boundary phase in the iron–oxygen alloys investigated by Mr. Rees and Mr. Hopkins is very striking. The oxide is clearly visible inside the grains, but there is no trace of any grain-boundary precipitate. This suggests that the embrittlement may be the result of a boundary-segregation process similar to that suggested for other forms of intergranular embrittlement. Presumably the authors would agree that the embrittlement of the iron–oxygen alloys could be caused by the segregation of oxygen atoms to the boundaries, which in some way reduces the cohesion across the interfaces. The effect of carbon or other



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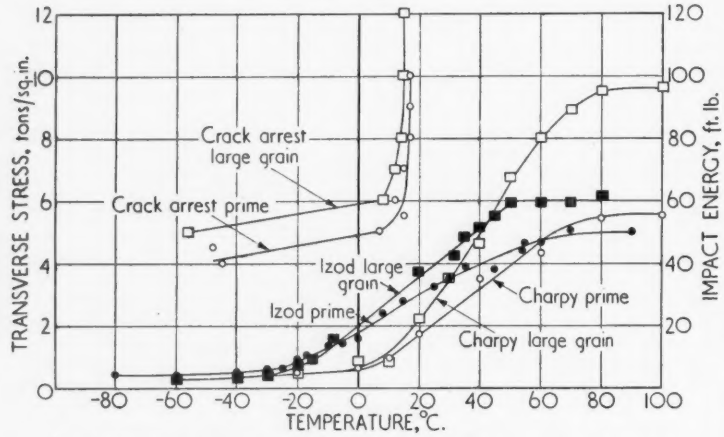

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Dr. **B. C. Woodfine** (B.I.S.R.A.): In regard to Dr. Petch's paper, it would seem at first sight to be very unlikely that three materials of such different composition as ingot iron, spectrographic iron, and mild steel would obey exactly the same cleavage-strength/grain-size equation, particularly since the specimens will contain different amounts of a second phase, depending on the heat-treatment used to obtain the final grain size. If the cleavage strength of iron is related to the grain size by the simple relationship suggested by Dr. Petch and is independent of carbon content from 0·036% to 0·155%, manganese content from 0·005% to 0·59%, and phosphorus content from 0·005% to 0·028% (to take only three examples), much of the work now being carried out on the effect of alloying elements on ferrite is apparently unnecessary; this position is hardly borne out by the results being obtained.[1, 5, 6] Varying the rate of cooling from the austenite region will not only produce different grain sizes but will also give different amounts of carbon in solution with corresponding variations in that precipitated as carbide; the distribution of carbide will also be altered and, with the slow cooling rates used to obtain the large grain sizes, grain-boundary films of carbide must occur. As shown in the paper by Mr. Rees and Mr. Hopkins, carbide films at the boundaries can initiate cleavage failure, so that under these conditions a deviation from any cleavage-strength/grain-size relationship would be expected.

In applying a strain correction taken from the work of other investigators to his fracture-stress results, Dr. Petch has assumed that the variation of cleavage strength with strain is independent of composition and grain size, without giving a justification for these assumptions. The work of McAdam, Geil, and Mebs[7] was concerned with an ingot iron and a mild steel different in composition from those used by Dr. Petch and was carried out at only one grain size. It would have been much more satisfactory if the dependence of cleavage strain on strain had been experimentally determined by Dr. Petch for the materials he used in the investigation, particularly since some of the corrections were apparently up to 30% or more of the measured value.

Dr. Petch claims that the lines showing the dependence of cleavage strength σ_c and lower yield point $\sigma_{l.y.p.}$ on grain size intersect at $l^{-\frac{1}{2}} = 0$, thus giving the same value of σ_0 in each equation. In Fig. 3 there is some indication that the lines actually intersect at a point above $l^{-\frac{1}{2}} = 0$, and if, in Fig. 1, the σ_c line is fitted to all the points, including those above $l^{-\frac{1}{2}} = 5$, the σ_c and $\sigma_{l.y.p.}$ lines will certainly intersect above $l^{-\frac{1}{2}} = 0$. It is clear from Fig. 3 that this must in fact be the case if the reduction in area has been measured accurately. No reduction in area means that $\sigma_{l.y.p.} \geqslant \sigma_c$, which according to Dr. Petch is only satisfied at $l^{-\frac{1}{2}} = 0$, so that above this point it should be possible to measure or observe some plastic deformation. However, the reduction in area for the ingot iron and mild steel is shown to be zero at $l^{-\frac{1}{2}} = 2{\cdot}5$ and $l^{-\frac{1}{2}} = 4$, respectively, so that clearly the σ_c and $\sigma_{l.y.p.}$ curves must intersect for ingot iron at $l^{-\frac{1}{2}} = 2{\cdot}5$ and for mild steel at $l^{-\frac{1}{2}} = 4$. Under these conditions, one of the claims made by Dr. Petch is wrong: either $\sigma_{l.y.p.}$, or most probably σ_c, is not identical for both materials.

The theory as presented in the paper neglects any interaction of dislocations with either solute atoms or precipitated particles, although Dr. Petch has indicated that he now considers that the σ_0 term in the equations will arise from this effect. If this is so, it is difficult to see how three materials with different carbon, alloy, and impurity contents and containing different amounts of a second phase can possibly have the same σ_0 term, as Fig. 1 apparently shows.

However, there are two more fundamental respects in which the theory is unsatisfactory; these are the effect of tri-axial stresses on cleavage fracture and the temperature dependence of the yield stress and cleavage strength. Dr. Petch states that cleavage, like the lower yield point, is concerned with stress concentrations produced by blocked glide planes, but he has apparently overlooked the fact that if cleavage is dependent on the presence of shear stresses, the cleavage strength should be raised by tri-axial stresses in the same way as the yield stress. If this is the case, the Ludwik–Orowan theory of notch brittleness requires reconsideration, and it is difficult to see how the phenomenon of notch brittleness could be explained. There is no reliable evidence to show that the cleavage strength is raised by tri-axial stresses, and the effect of increasing tri-axiality on the ductile–brittle transition indicates that yield and cleavage are not affected in the same way. Similarly, from the results of Eldin and Collins[8] the effect of decreasing temperature on yield and cleavage is far from identical, indicating that the controlling mechanism of each process is not the same, as Dr. Petch's theory would indicate.

Although Dr. Petch states that some results for single crystals are included in Fig. 1 he does not indicate how his theory can explain the cleavage fracture of these crystals. Clearly, any stress concentration developed by slip must occur outside the surface of the crystal and cannot lead to subsequent cleavage fracture.

In Fig. 1 $l^{-\frac{1}{2}}$ is proportional to the average grain diameter, but if stress concentrations produced by blocking of dislocations are to lead to failure, then surely —since in the theory Dr. Petch has considered the source at the centre of the grain to give the greatest stress concentration—in applying the theory he should use not the average grain diameter but the maximum grain diameter found in the specimen. The largest grain is much more likely to initiate fracture than the smallest grain. Has Dr. Petch considered his results from this point of view ?

How is the conclusion reached by Dr. Petch " that subtle effects of composition are possible owing to the segregation of solute atoms to (the grain-boundary) region " correlated with Fig. 1, where a complete independence of composition and heat-treatment is shown ?

The absence of a grain-boundary phase in the iron–oxygen alloys investigated by Mr. Rees and Mr. Hopkins is very striking. The oxide is clearly visible inside the grains, but there is no trace of any grain-boundary precipitate. This suggests that the embrittlement may be the result of a boundary-segregation process similar to that suggested for other forms of intergranular embrittlement. Presumably the authors would agree that the embrittlement of the iron–oxygen alloys could be caused by the segregation of oxygen atoms to the boundaries, which in some way reduces the cohesion across the interfaces. The effect of carbon or other

alloying elements in reducing intergranular embrittlement can be envisaged qualitatively if the carbon atoms segregate preferentially to the grain boundaries and thereby prevent oxygen atoms from accumulating and reducing the cohesion. It is very difficult to consider segregation processes theoretically because there are so many unknown factors, but it seems to be a strong possibility that if radioactive tracers could be introduced into iron much more might be learnt about grain-boundary segregation.

It is interesting to note how much attention has recently been given to intergranular failure in both steels and irons, and how it recurs under various conditions in these materials. It is always necessary to bear in mind, when attempting to interpret results, that the presence of only a small percentage of intergranular fracture in the final failure may mean that the mechanism controlling fracture is the intergranular cohesion. If only a few grains fail across the boundaries, it may be that the cracks produced in this separation control the final failure of the specimen.

Mr. **W. P. Rees** (National Physical Laboratory): I have plotted the results given in the N.P.L. paper[1] on tensile and impact properties of low-carbon Fe–C and Fe–C–Mn alloys on the same graph as Dr. Petch has used (Fig. *E*). Whilst there is some dependence of cleavage strength on grain size, almost the same cleavage strength can be obtained along the line of grain sizes corresponding to $l^{-\frac{1}{2}} = 3$–$7\frac{1}{2}$. Similarly, for the same grain size of 9 grains/mm. there can be a difference of fracture strength of about 10 tons/sq. in. There are obviously other factors in addition to that of grain size affecting the cleavage strength.

I should like to take this opportunity to criticize the tendency to reproduce illustrations in the *Journal* in the smallest space. I realize that this is done for economy, but in graphs which present a large number of results it is not obvious at first sight that there is a spread of $\pm$ 6 tons/sq. in. The absence of Tables means that there is no way of ascertaining the individual heat-treatments to give the grain sizes. How did Dr. Petch get a grain size corresponding to 8000–9000 grains/sq. mm. by air-cooling a mild steel ?

CORRESPONDENCE

Dr. **G. W. Greenwood** and Professor **A. G. Quarrell** (Sheffield University) wrote: We have recently investigated the effects of grain size, plastic deformation, temperature, and strain rate upon the cleavage strength of polycrystalline high-purity zinc. The results show that there are many points of similarity in the cleavage behaviour of steel and zinc, as well as some differences, and a brief summary may be of interest in connection with Dr. Petch's paper.

When tested in tension at $-196°$ C. all the zinc specimens fractured by cleavage without measurable overall plastic deformation, although the cleaved grains were heavily twinned. The cleavage strength σ_c was inversely proportional to the square root of the mean grain diameter l, so that $\sigma_c = kl^{-\frac{1}{2}}$. This relationship is the same as equation (3) of the paper but with $\sigma_0 = 0$.

It would be of great interest to know whether the relationship $\sigma_c = \sigma_0 + kl^{-\frac{1}{2}}$ is valid for other metals which show cleavage. We have found that it does not hold for pure magnesium. It would perhaps be worth investigation to determine whether the relationship holds for pure molybdenum, since there are indications that this metal shows increasing susceptibility to cleavage with increase in grain size.

An important difference between the results for steel and those for zinc lies in the effects of plastic deformation before fracture. The cleavage strength for steel is

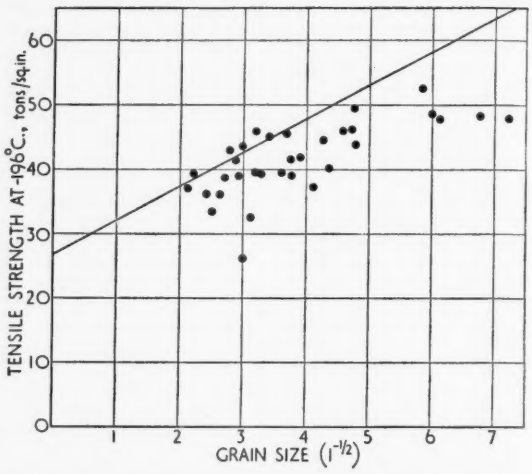

Fig. E—Tensile and impact properties of low-carbon Fe–C and Fe–C–Mn alloys

increased by pre-strain; in our experiments, that for zinc was decreased by pre-strains ranging from about 5% to 25%. This is probably associated with lack of twinning during fracture after plastic deformation in this range.

When the measured cleavage strengths were corrected for the effect of plastic deformation, the results showed that the cleavage strength for zinc increased with temperature. The equation $\sigma_c = kl^{-\frac{1}{2}}$ was still valid, but the constant of proportionality k increased by a factor of about 3 in the range $-196°$ to 20° C. On the dislocation theory of cleavage this increase can probably be attributed to stress relaxation at the higher temperatures. It is markedly against the direct application of the unmodified Griffith crack theory, which predicts a decrease in cleavage strength because of the decrease of surface energy and Young's modulus with increase in temperature.

It is implicit in Dr. Petch's argument that cracks do not exist before the metal is stressed, since the necessary stress concentration for cleavage is assumed to develop as dislocations become piled up on the slip planes under the applied stress. Thus, the dislocation theory of cleavage removes a major difficulty previously associated with the application of the Griffith crack theory to metals.

In addition to predicting the correct type of relationship between σ_c and l, as pointed out by Dr. Petch, the dislocation theory of cleavage predicts values of k in equation (3) which are of the correct order of magnitude. Using the nomenclature in the paper, $k = \sqrt{(8A\sigma_{\text{t.c.s.}}/\alpha)}$. The orders of magnitude of the various quantities are generally known for any metal to be as follows:

Theoretical cleavage strength $\sigma_{\text{t.c.s.}}$ of the order of 10^{12} dynes/sq. cm.
Parameter $8A$ of the order of 10^4 dynes/cm.
Constant α of the order of unity.

Assuming these values, K is then of the order of 10^8 (dynes/sq. cm.)/sq. cm. compared with 2×10^8 (dynes/sq. cm.)/sq. cm. read from Fig. 1 and 1–3×10^8 (dynes/sq. cm.)/sq. cm. for our own results for zinc in the range $-196°$ to 20° C.

The theory also leads to a reasonable estimate for the number of dislocations that must be piled up for fracture to occur. Thus in a specimen of mean grain diameter 10^{-2} cm., about 10^3 dislocations are required between

the source and the boundary to build up a stress concentration necessary for cleavage.

The theory would seem to present a most promising approach to the understanding of the mechanism of cleavage, and refinements would seem to wait on further developments in the theory of dislocations.

AUTHORS' REPLIES

Dr. **J. H. van der Veen** (in reply): In answer to Mr. Honeyman, the test is principally adiabatic and not isothermic. For a specimen taken from a bath of — 35° C., the temperature rise by contact with the surroundings has been found to be only ½° C./min., and the test is carried out in ½ min. There is thus no temperature rise as a result of heating by surroundings.

Another question was whether the temperature would rise as a result of deformation of the test piece. To avoid that, the test piece would have to be surrounded by a cooling medium (and also during bending) and the test would have to be done very slowly to enable the heat generated during the propagation of the fibrous crack to be dissipated *via* the whole test piece into the bath. We therefore considered that it would be better to keep the test an adiabatic test, as it would be far more practical and more similar to practice. Moreover, there would not be any errors in those temperature regions where fracture was entirely brittle, and thus no error would be made in the determination of the maximum temperature for brittle fracture.

From the point of view of strength the two steels in Fig. 9 were of the same type, but not from the point of view of manufacturing process. The steel having the high long curve was a fully-killed steel, containing silicon and aluminium, but the other was a rimming steel. This is, however, not considered essential, because analogous differences have been found between steels of the same manufacture owing to differences in the amount of banded structure.

Dr. Allen asked whether the fact that scatter in a notch-bend test was less than in the Charpy **V**-notch test might be due to the fact that in the notch-bend test there would be a better sample of steel because of the larger dimensions, or whether the difference in scatter was caused by the fact that in the Charpy **V**-notch test it would be more a test on the energy absorbed in initiating a crack. I have never carried out tests on an entirely homogeneous steel, and so I cannot say whether the difference is due to the type of test or to fluctuations in the steel. We have encountered fluctuations on several occasions in the steel plate itself, which had a wavelength larger than the dimensions of the notch-bend test. In one of these cases we were very lucky, in that the scatter of the notch-bend test itself was not high, so that we could draw two different transition curves. We found afterwards that all the specimens belonging to the 'worst' of the two curves had a larger grain size and had been cut from a strip of the plate which had evidently had another heat-treatment or cooling rate. We could not find out the technical origin of the scatter because it was not a plate from our factory.

In regard to Dr. Allen's remarks about notch-bend testing, we must still bear in mind that whether or not there is really progress depends in a sense on the criterion used, for it might be possible, if the wrong criterion were used, to develop a so-called 'improved' steel that would in fact not be much better than the previous types. That is why the question of the right criterion for brittle fracture must be solved soon; that can be done only by comparing tests and criteria on plates whose service performance is known and in which we try to find out which of the criteria applied shows the best relation with behaviour in practice.

In reply to Dr. Wells, we have never applied this test to other materials, but I think it can be more widely applied, although in some materials the pressing of the notch may not be possible. In those cases a milled notch could be used.

Dr. **C. F. Tipper** and Dr. **E. O. Hall** wrote in reply: A full account of the work referred to by Dr. Allen and Mr. McLennan on iron crystals will be looked forward to with great interest. It has been shown in the present paper and elsewhere[9] that Neumann lamellæ will form under conditions of shock in material which has been plastically deformed and under temperature conditions at which they are not normally produced. This seems to imply that a higher stress is required for the production of Neumann lamellæ compared with slip, certainly in polycrystalline material.

Dr. Wells asks whether the authors have abandoned Sohncke's law for α-iron crystals. They have merely shown that, with the few crystals at their disposal, the stress normal to the plane of fracture was not constant, but the load to fracture became less as the angle between fracture plane and tensile stress approached 90°. Sohncke's law has been abandoned for cleavage fracture of zinc,[10] but a final verdict for the case of α-iron must await the testing of more crystals.

In regard to the development of surface markings on fracture surfaces, it would appear that the similarity of form and shape in such markings on widely different materials must have some common explanation. It has been suggested that these marks are caused by the halting of the fracture and re-initiation at a different level. There are several reasons for a fracture to be arrested and started again. Whatever the cause, a halt implies a momentary change in velocity.

Mr. Burns's observation that crack formation causes minute jogs on the stress/strain curve and an audible 'click,' such as occur with the formation of Neumann lamellæ, is to be expected. In both cases, a sudden extension occurs with a drop in load, the magnitude of which depends upon the extension and stiffness of the system. Subsequent examination proves which has taken place, as Mr. Burns was able to show.

We wish to thank those who contributed to the discussion for comments which may be helpful in future work. We are gratified to find that later work has confirmed many of our results.

Mr. **W. P. Rees** and Mr. **B. E. Hopkins** wrote in reply: Grain-boundary segregation of oxygen is the simplest explanation of the embrittlement of iron by this element, in view of the increasing weakness of the grain boundaries as the oxygen content is raised and the absence of any evidence of oxide films along the boundaries. As Dr. Woodfine remarks, the use of radioactive tracers would be expected to give direct evidence of such segregation in suitable cases, but no radioactive isotope of oxygen with a reasonable half-life exists. It is difficult to decide whether the segregation should occur whilst the material is austenitic or ferritic, since there seems to be no quantitative information on the mobility of oxygen in iron. The major part of the segregation might well occur in the austenitic region. In reply to Mr. Sage, most of the ferrite grain boundaries in our alloys are likely to have been the same as the austenite boundaries, so that the occurrence of fracture along the ferrite grain boundaries does not preclude the possibility of segregation of oxygen atoms having taken place while the materials were in the austenitic condition.

We would not like to attach much importance to the crossing at the bottom end of the impact-value/temperature curves of the 0·007% and 0·011% oxygen alloys mentioned by Mr. Sage. The effect is small and may not be significant.

Dr. Wells and Dr. Pratt have asked about the practical importance of intergranular failures. We have not examined service failures; the fractures in the mild-steel ship plate mentioned in the paper were produced in the laboratory. We have found, however, that brittle fractures produced in commercial materials can be partly intergranular, although this may not be attributable to oxygen. The importance of this is that the start of brittle fracture in such examples is governed by the grain-boundary strength, which is less than the cleavage strength and thus results in a higher temperature of transition from tough to brittle fracture than if the behaviour were controlled by the cleavage strength.

In reply to Mr. Honeyman, grain growth in high-purity iron alloys occurs very readily at all temperatures above about 600° C., and we have experienced difficulty in obtaining fine grains by cold-working and annealing.

Dr. **N. J. Petch** (Leeds University) wrote in reply: A principal concern in the discussion has been the possible effects of differences, other than of grain size, produced by the different cooling rates in my experiments. Since publication of the paper, this point has been examined in greater detail in collaboration with Mr. Cracknell and Mr. Heslop in an attempt to elucidate the cause of the σ_0 term.

We do not now consider that interaction with neighbouring dislocation arrays is responsible, but this is not for the reason suggested by Dr. Allen, who speaks of single dislocations, whereas the paper referred to arrays. The friction due to interaction with random carbon and nitrogen solute atoms and with the internal stresses due to fine precipitates seems to be a more likely cause, and we have shown experimentally that they are in fact principally responsible for the σ_0 term in the lower yield point at room temperature. This σ_0 is 4–5 tons/sq. in. for annealed steels and increases to 8–9 tons/sq. in. on quenching and to about 10 tons/sq. in. on subsequent ageing, but decreases again as the precipitates become more dispersed on over-ageing. This alteration in σ_0 has a marked effect on the lower yield point at room temperature, and the impact transition temperature is raised by about 20° C. on quenching. However, the alteration in σ_0 is temperature-independent, so that the effect in liquid nitrogen is proportionally much less. Thus, the difference between annealing and quenching only produces a difference of about 5 tons/sq. in. in the cleavage strength at constant grain size in liquid nitrogen, so that the variation in the cooling rates in the present paper from furnace-cooling to air-cooling in a silica tube will be unimportant.

Mr. Burns describes some interesting results that suggest that the γ rather than the α grain size is important, but my feeling is that if the γ grain size had a direct effect he must have got his steel into a condition that gave intercrystalline fracture around the austenite boundaries. However, the effect may be indirect; he would have to cool his coarser austenites more quickly than the fine ones to obtain the same ferrite size, and the effect of faster cooling on the retention of solute atoms and on the formation of fine precipitates in the ferrite would, as mentioned, be detrimental to the transition temperature; this possibly accounts for his results. Mr. Burns also raises the question of more than one cleavage crack per grain. In the paper it is assumed that the highest stress is required to initiate cleavage; the actual path of the cleavage crack probably will be complicated, but this will be immaterial provided that the propagation stress does not exceed the initiation stress.

In addition to the part of σ_0 due to solute atoms and precipitates, there is another part that possibly represents the stress required to force a dislocation through other dislocations that intersect the glide plane. This part is very temperature-dependent; it is about 2 tons/sq. in. for ferrite at room temperature and about 28 tons/sq. in. in liquid nitrogen. Consequently, the cleavage strength should be temperature-dependent, in agreement with Mr. McLennan's single-crystal results. The interesting variability in the single-crystal behaviour may indicate that the formation of the internal blockages is orientation-dependent.

Dr. Woodfine considers that the theory is fundamentally unsatisfactory in two respects. His objection on the basis of the different temperature-dependence of yielding and cleavage established by Eldin and Collins is unsound. The similarity between yielding and cleaving suggested in my paper is only in the mechanism of stress-concentration; the temperature-dependence of the concentrated stresses that must be generated in one case for yielding and in the other case for cleavage will be different. There is a need for a reconsideration of the theory of a notch and the evidence that tri-axial tension raises the cleavage strength. In his difficulty in understanding the cleavage of single crystals, Dr. Woodfine has overlooked internal blockage. His reasoning from the reduction-in-area figures is unreliable, because of the uncertainties in these figures that must occur unless the strain at fracture exceeds the yield-point strain. It is incorrect to say that the maximum grain diameter should have been used; the largest grain does not necessarily contain the longest array, nor is this grain necessarily in the orientation for maximum shear stress on the glide plane. Dr. Woodfine considers that my results rule out the possibility of composition effects, but the range of compositions used was limited and it is still quite possible that interesting effects may occur, particularly at high purity or in the presence of alloys. We have now determined our own strain correction, but it does not affect the results.

The very interesting contribution from Mr. Robertson serves to emphasize the complication of fracture problems and shows that, although fine grains give a high cleavage strength, coarse grains may be advantageous in the arrest of a running crack, because of the consequent large plastic work when the fracture changes towards a ductile nature.

Mr. Boyd's concept of fracture by the successive breaking of atomic bonds resembles that of Poncelet[11] and Saibel.[12] The difficulty is that this process proceeds with an increase in free energy until the critical Griffith crack size is reached and, since a crack about 1000 atoms long is required, the activation energy is prohibitive.

The plastic-work function mentioned by Dr. Pratt presents many difficulties. I think it is fair to emphasize the complete lack of adequate knowledge about its magnitude. Thus, Orowan's estimate refers to the spread of a crack out from some source into previously undeformed steel at room temperature and consequently will probably be very different from the value appropriate in liquid nitrogen for a steel that has been uniformly deformed until a crack is initiated. Also, it is uncertain how much of the observed plastic work precedes and how much follows the passage of the crack. Furthermore, although the substitution of plastic work for surface energy in the Griffith argument is straightforward, it is not so clear what this means when stresses are considered, nor is it very clear what the relationship is

to the assumption made in my paper, namely that a constant critical normal stress is required at the stress concentration. Dr. Pratt considers that small cracks are linked together during the plastic deformation of the fine-grained specimens, but I prefer to suppose that initially the stress concentration at the arrays is relieved by plastic deformation, and eventually cleavage becomes easier than further deformation.

In regard to Fig. *E*, Mr. Heslop and I have experimentally confirmed the $\sigma_c = \sigma_0 + kl^{-\frac{1}{2}}$ relationship a number of times since the publication of my paper, so possibly Mr. Rees may obtain interesting information from an examination of the deviations he observes. The 8000–9000 grains/sq. mm. were obtained from $\frac{5}{16}$-in. bar.

The support of Dr. Greenwood and Professor Quarrell for a dislocation theory of cleavage is very pleasing. Measurements carried out with Mr. Zein on zinc are in general agreement with those they describe, although we think there may be a small σ_0 ($< \frac{1}{2}$ ton/sq. in.) with our zinc and, although we get a maximum at 5–10% in the effect of prestrain on the cleavage strength and the effect is small, we have not obtained strained specimens with strengths lower than the unstrained ones.

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Discussion on the Paper—

THE WATER-COOLING OF OPEN-HEARTH FURNACES* *By A. M. Frankau*

Mr. **A. M. Frankau** (B.I.S.R.A.) presented his paper.

Mr. **Y. A. Calderwood** (Wellman Smith Owen Engineering Corp., Ltd.): There appears to be a complete lack of uniformity in this field, and Mr. Frankau's figures tend to confirm this: *e.g.*, the very high figure of 36 tons of water circulated per ton of steel made, and the case where the temperature rise of the cooling water is only 3·9° F.

No doubt there are several reasons for these variations, but the most important is given in the paper: "The quantity of water needed for circulation depends more on the quality of the water used than on the temperature rise between inlet and outlet." In many cases this factor of water quality determines the method to be used for water-cooling, and for this reason it would be an advantage in future papers on this subject to have stated the source of supply of the water and the means of circulation.

The loss of heat by cooling water in terms of money can be serious. Curphey[1] quotes a figure of 2*s.* per ingot ton for a heat loss of 10% of the total heat input, which may be considered a minimum figure. Mr. Frankau quotes maximum losses equivalent to 1400 gal. of fuel oil or 10 tons of gas-producer coal per day, worth at present about £53 and £32, respectively. These seem to be net figures, since Mr. Frankau states that "any measured heat losses can be increased by at least a half to give the heat input required."

My company were asked by B.I.S.R.A. to give their views on the proper application of water-cooling. This is not simple, since the number of cooling units which should be used on an open-hearth furnace is a matter of opinion, and can depend upon local considerations. Perhaps the best approach to this request is to ask how seriously the steel industry is going to tackle the problem. Our general experience is that on an open-hearth plant the main water-inlet valve is turned on full at the start and stays full open.

To tackle the problem properly will be expensive, involving the use of measuring instruments and possibly automatic control or special hand-control valves. Alternatively, we can follow German practice and materially reduce the water requirements by replacing water-cooling by the use of low- or high-pressure steam. In this system, which is still in the experimental stage, hot water is circulated, the steam evolved is extracted, and the hot water remaining is recirculated. The amount of water circulated is 5–10 tons per ton of steel made, which is appreciably lower than the amount used in normal practice.

Dr. **A. H. Leckie** (B.I.S.R.A.): It might be thought that because water flow and temperature rise can be measured relatively easily the magnitude of heat losses due to water-cooling would be well known. The fact remains that these losses have been accepted with apparent equanimity until quite recently.

One of the biggest sources of heat loss is at the door frames. It is often said that the chief reason for water-cooling a door-frame is that charger drivers will knock down the brickwork of an ordinary door opening without this type of protection. If this is so, the relative merits of small and large doors should be considered, because, to get a large amount of material in quickly with the minimum damage to the frames, the door should presumably be as large as possible. On the other hand, that will mean a greater heat loss both through air infiltration and through water-cooling. Has the author considered all these aspects with a view to minimizing water-cooling losses as well as just measuring them ?

At the water seals in the tilting furnace referred to in the paper, the heat loss is quite small in the first week and the seventh week, and then in the sixteenth week it suddenly jumps up. There has been an increase in the flow of water and in the temperature rise, yet this is a position where such a drastic rise would not be expected. This point might be further examined. Moreover, why is it necessary to have water seals in that position ?

* *J. Iron Steel Inst.*, 1953, vol. 174, May, pp. 46–52.

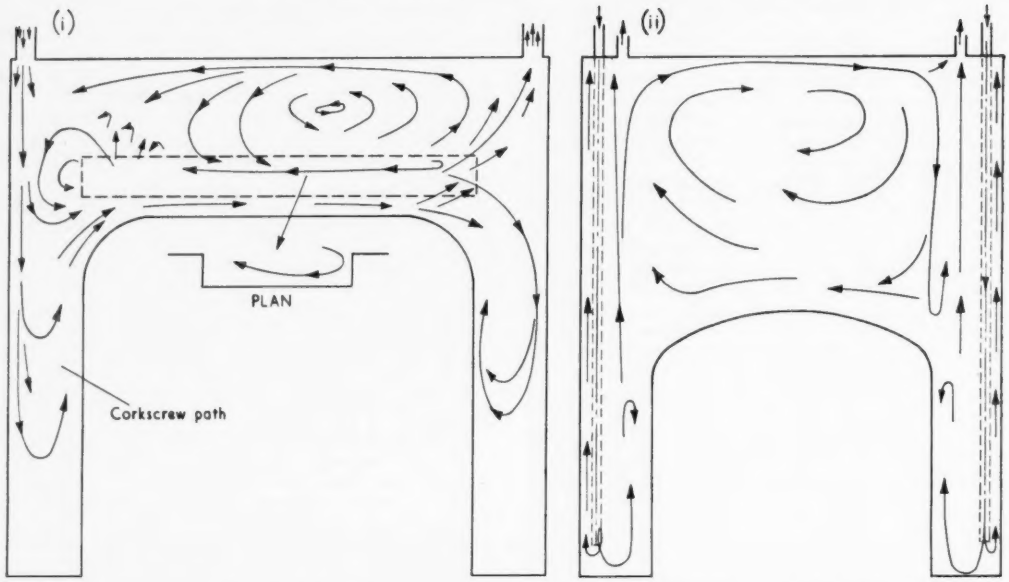

Fig. A—Open-hearth door designs, showing water flow. In (ii) in coming water flow is greater in the left-hand inlet

Would the use of sand seals not be equally effective, thereby minimizing this heat loss?

Mr. **C. R. Banks** (Blaw Knox Ltd.): This paper, although excellent, does not go so far as it might, in that it only studies the losses resulting from water-cooling.

With the exception of furnace 2 in the fixed-furnace group, the author's figures would no doubt obtain in many other plants. Furnace 2 is apparently almost identical with furnace 3, yet it shows a loss of 27·6%, compared with 18·3% in furnace 3. It might at first be thought that furnace 2 was nearing the end of its campaign and that the brickwork was wearing thin, but the figures show that furnace 3 was actually in operation nine weeks longer, so that there must be some other reason for this extraordinary jump, apart from the furnace pressure, which the author mentions. Has he enquired about the reason for this abnormal condition?

The author states some of the advantages to be derived from the use of water-cooled fitments, but his figures are not very convincing. His suggestion that a particular furnace is losing the equivalent of 1400 gal. of fuel oil per day implies erroneously that there might be an easy way of improving fuel practice. This loss cannot be made good by eliminating water-cooling. Again, Table V gives the heat losses which might obtain if water-cooling were dispensed with. I realize that these figures were given as a yardstick for comparison with a water-cooled furnace, but the estimates give a completely wrong picture, because if water-cooling were dispensed with there would soon be an increase in the number of front-wall repairs, causing a drop in steel production and an increase in fuel per ton.

Melting-shop managements and engineers are familiar with the amount of cooling water that goes into the melting shop, which indicates that the author's test figures are not new. Above all, they figure in the cost sheet, and so water-cooling must either prove its worth or be dispensed with.

Water-cooling is used extensively in steel plants because it keeps a furnace in good shape for a longer period, it helps to maintain tightness around the doors, and it does much to eliminate hot repairs. The combination of these factors makes for an efficiency which is not unduly diminished during the campaign of a furnace, and that is most desirable. As such it is closely related to fuel consumption.

In the case of producer-gas furnaces, efficiency largely depends on having a consistently good shape of flame throughout the campaign to maintain the melting rate. This can only be satisfactorily achieved with water-cooling around the ports.

These factors have to be balanced against the losses to decide whether water-cooling is worthwhile; there is no doubt that this must have been done by most of the plants using water-cooling and it must have been justified.

I do not believe that water-cooling is the beginning and end of furnace efficiency, but at the present time and in the foreseeable future it is absolutely essential.

Mr. **M. P. Newby** (B.I.S.R.A.): There is another aspect of the problem of water-cooling, namely, the quantity of water used in the system. The heat loss depends mainly on the overall furnace design, but the quantity of water used depends mainly on the internal design of the water-cooling system.

A dead zone of no circulation in a water-cooling system is very inefficient and must be eliminated completely. Zones of low water velocity, where the water-cooling is poor, must also be eliminated; if the water velocity is high enough in the worst points it will be much too high at the good points, and a great deal of water will be wasted.

Figure *A* (i) shows an actual design of water-cooled open-hearth door frame, where the bottoms of the two legs have zero circulation. This is an appalling design, but it is actually used in practice.

Figure *A* (ii) shows a better system. The distribution is much more even, which gives a more economical use of water-cooling. It shows how simple changes of design can improve enormously the quantity of water needed to cool a door frame.

Mr. J. H. Flux (United Steel Companies, Ltd.): Mr. Frankau has compared the heat losses from a water-cooled door frame with the estimated heat flow through a furnace wall, and under those conditions the use of water-cooling does not appear attractive. The attempt to give a ' yardstick ' by quoting the losses which occur in an uncooled furnace does not go far enough.

With a water-cooled door frame, the door fits well and ' sting out ' is reduced to a minimum. A water-cooled door frame and door is a much better sight than the typical door, which is half burnt away, with bricks dropping out of the middle and with flame spurting out in all directions. Attention has been drawn to the fuel input required to make good the heat carried away by the cooling water, and yet improved fuel consumptions per ton of steel manufactured are being obtained on furnaces where water-cooling is extensively practised.

The author should attempt, therefore, to establish more realistically the losses which can occur in uncooled furnaces and then prepare a ' balance sheet ' to establish the comparative economics of the use of water-cooling against that of uncooled furnace components. In particular, if allowance is made for the reduced furnace front-wall maintenance time with water-cooled frames, their use will not appear so unattractive as this paper suggests.

Two examples of the circulation of water through a door frame have been shown, but I thought the design shown in Fig. *A* (i) was abandoned many years ago, when it was appreciated that it was essential to introduce the cold water at the hottest parts of the frame and also to provide for fairly vigorous circulation. The design shown in Fig. *A* (ii) is not in very common use today; the outlets are more central and so avoid those areas of non-circulation at the top of the frame. To give even better cooling, the inlet pipes passing through the frame to the bottom of the legs might be perforated.

The use of steam-cooling has been advocated; whilst this does not reduce the loss of heat from the furnace it improves the recovery of waste heat. On an 80–100-ton cold-metal furnace three steam-cooled door frames will together generate about one-third of the steam which would be generated by a waste-heat boiler on the same furnace. The capital cost of the steam-cooling equipment would be about the same as that of a waste-heat boiler per pound of steam, but there are advantages on water utilization and furnace maintenance that tend to suggest that steam-cooling is advantageous.

Mr. **Banks**: Figure *A* (i) was described as a door frame actually in use; that is inaccurate. The sketch shows the outline of an archless-type frame having only water inlet and outlet connections with no means of internal water distribution, and the water flow pattern was obviously taken without any heat being applied to the frame. The application of heat makes a very big difference to the flow pattern. The crude circulation shown would not work out in practice. Actually, this type of frame has a very efficient water-circulating system successfully developed over many years.

Mr. **A. L. Cude** (B.I.S.R.A.): When any heat is transferred from the gases in the working chamber of a furnace, there remains a residue of hot waste gases which cannot be cooled down to less than the temperature of that chamber, so that a further large amount of heat is removed. Some of that heat is recovered by the regenerators and recirculated, and the rest is lost up the chimney, with the result that any measured heat loss from the furnace must be multiplied by some factor to get the true wastage of fuel which that heat loss represents.

In the case of the open-hearth furnace, that factor is about 2. When that is applied to the measured water-cooling heat losses, the resultant wastage of fuel may be very high indeed (nearly 40% in some cases). Present-day fuel prices, particularly those of oil fuel, are too high for this fuel to be wasted. Some of those losses are, of course, unavoidable (they take place in any case and just happen to be intercepted by the water-cooling), but it would be worthwhile to pay attention to the exposed water-cooled surfaces on the inside of the furnace to eliminate all unnecessary cold surfaces.

AUTHOR'S REPLY

Mr. **Frankau** (in reply): The problem of fuel economy, to which water-cooling relates, should be in our minds at all times. These experiments were carried out to assess the heat lost to the cooling water with the ultimate aim not of eliminating cooling units, but of redesigning them both to reduce water flow and heat loss. I agree with Mr. Banks that cooling is essential to keep the furnace shape and cut down the repairs.

In reply to Mr. Calderwood, the water supply to the first fixed furnace was mainly corporation water with a total hardness of 9°. The second and third fixed furnaces drew their water from an impounded dock and the total hardness was 30°. The tilting furnace drew its water from a local stream which at the time of the tests had a hardness of 13½°: in the summer this water is said to become much harder.

The size of door opening has been considered, but primarily from the aspect of charging the open-hearth furnace. Dr. Leckie would probably agree that if larger doors were provided larger charging boxes would almost certainly be used. The door frame is used not only to afford protection against damage, but also to provide a good seal for the door. The increase in heat loss from the water seals at the gas and air uptakes was, in the author's opinion, entirely due to erosion of the brickwork at this level, by impingement of the exhaust gases. Some alleviation of this wear has been obtained by the insertion of a flat cooler in the back wall just above the seal.

The considerable difference in heat loss between the second and third fixed furnaces has been questioned by Mr. Banks. As shown in Table III, this is almost entirely caused by the differences in heat loss at the tunnel coolers over the oil burners. A possible explanation has been given, but there might also be some small difference in construction which might cause this difference.

Mr. Newby pointed out that the flow pattern of the water in cooling units can have a profound effect on the quantity of water that is required to circulate. This in itself will not, of course, affect the heat loss, but it is an important consideration in new designs, as the pumping costs of the water are by no means negligible.

In Germany experiments are being made on the use of the heat losses from doors and door frames for steam raising, mentioned by Mr. Flux, and three papers on the subject appeared recently.[2–4] This application may well be worth watching.

If this paper has drawn attention to the losses that occur and to the fact that these can be reduced by a little extra protection of the cooling units to prevent direct radiation from the furnace falling on them, something will have been achieved.

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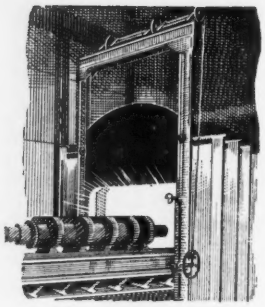


IRON AND STEELWORKS ENGINEERING

THE IRON AND STEEL ENGINEERS GROUP

THE IRON AND STEEL ENGINEERS GROUP

REPORT OF THE TWENTY-THIRD MEETING

THE TWENTY-THIRD MEETING OF THE IRON AND STEEL ENGINEERS GROUP of the Iron and Steel Institute was held at the Offices of the Institute, 4 Grosvenor Gardens, London, S.W.1, on Wednesday, 28th October, 1953. Mr. C. H. T. WILLIAMS (The Park Gate Iron and Steel Co., Ltd.), Chairman of the Group, presided.

The MORNING SESSION was devoted to the presentation and discussion of a paper entitled " Roll-Design Research as Applied to Rolling-Mill Development," by Mr. B. ROBINSON and Mr. W. A. LUGAR (The Park Gate Iron and Steel Co., Ltd.).

The AFTERNOON SESSION was occupied by the presentation and discussion of a paper by Mr. W. BAILEY (Davy and United Engineering Co., Ltd.), entitled " Manipulating Equipment, Guides, Guards, and Strippers for Rolling Mills."

The discussion of this paper appeared in the June issue of the *Journal.*

PROCEEDINGS OF THE MORNING SESSION: 10.30 A.M. to 12.45 P.M.

Discussion on the Paper—

ROLL-DESIGN RESEARCH AS APPLIED TO ROLLING-MILL DEVELOPMENT*

Mr. **Bernard Robinson** presented the paper.

Mr. **J. M. McLaughlan** (Appleby-Frodingham Steel Co.): Mr. Robinson gives only a partial explanation of the methods of finding where the pitch line ought to be relative to the pass. Will those who examine Fig. 3 realize that what is required, after having placed a pass on a piece of paper and drawn two vertical lines on the outside, is to draw the line *BC*, and that it does not matter where that line is? The area of the pass may or may not be used, but if it is not used a similar arbitrary line is drawn at the top to find the mean ordinate. When the two datum lines, one for the bottom and one for the top, have been obtained, the length in between is bisected, giving the position of the pitch line. A channel finishing pass or the penultimate pass may have the roll joints above or below the pitch line and it must be agreed that in the application of the formula the position of the roll joints is not taken into consideration, whereas it has an important relationship to the position of the pitch line.

Table II is an example of estimated possible tonnages, varying from 15 to 65 tons/hr., for a proposed new rolling mill. Is it considered a good thing to attempt either to design or to choose a mill with such a big variation in the rolling output? There is a large section mill at Appleby-Frodingham which has an output range of the same tonnage and the orthodox view is that the mill should always be rolling at the higher rate.

What type of furnace and heating capacity is considered suitable for such a large range in rolling rate?

Is the Mogiljanski slide rule really worth anything at all, since it can only be applied to rectangular sections or plain sections such as flats and blooms? A pass should only be resolved into a rectangle if it is fairly near a rectangle to start with.

Mr. **Robinson:** We thank Mr. McLaughlan for explaining the Lennox method of finding the position of the pitch line which we had not made clear. What we are actually doing with the pitch line is analogous to the determination of the mean effective pressure from a steam-engine indicator diagram. We find the average working diameter of the bottom roll and the average working diameter of the top roll within the pass. For smooth rolling those two should obviously be equal, and that is the basis of the introduction of this method.

Many rolling mills are called upon to roll sections of differing throughputs per hour as for example the mill at Appleby-Frodingham which Mr. McLaughlan mentions and we suggest that the best method of dealing with this problem from the heating angle is to install two furnaces of 35 tons/hr. capacity each. This allows the mill to work one or two furnaces as required according to the section being rolled.

Mr. **W. A. Lugar:** The Mogiljanski slide rule was developed by the late Mr. A. B. Mogiljanski for the interpretation of Ekelund's formula for rolling load. Mogiljanski checked the Ekelund formula against the mill at the Wicowicz Iron and Steel Works and made the slight modification which has been incorporated in the rule. To make a check myself, I had to take Dr. Puppe's test on a 43-in. cogging mill. I was disappointed with

**J. Iron Steel Inst.*, 1953, vol. 175, pp. 183–197.

the first results ; when one examines the temperatures it looks rather strange in a cogging mill to find not a drop in temperature but an actual rise, whereas in Waldorf's test on a 35-in. 3-high mill rolling an ingot of similar size, with tests conducted only 20–25 years ago, when presumably pyrometers would be more reliable than in Dr Puppe's day, there is definitely a fall in temperature in every pass, even with a very heavy draft of as much as 4½ in. It made me think that Puppe's temperatures were too static, and so I decided to adjust them to give a similar fall in temperature per pass. The results are incorporated in Table IV, in addition to those of the Timken tests. I thought that the Ekelund formula as interpreted by the Mogiljanski slide rule would be quite reliable for our proposed mill.

Mr. **W. Craig** (Davy and United Engineering Co., Ltd.): I should like to comment from the engineering aspect. Figure 1 shows the rolling procedure for various profiles, particularly beams and channels, to roll which we require these abnormally big collars on the top or bottom roll, which introduce abrasion and friction in rolling. Should not research aim at rationalizing the shape of some of these profiles for more efficient rolling ?

In Fig. 2 the authors give a very neat example for fixing roll centres. They start with a given draft and contact angle and arrive at a roll diameter of 36 in.; they then add 4 in. for reduction in diameter from new to scrap and 5 in. for collars, and finally get the rolls up to 45 in. This is a very large mill. Why do we need to go to 45 in. ? Could we not stop at 40 in. and have a smaller mill for that job ?

The sketches of mill layouts could have been amplified a little and made plainer. Figure 5, a 40-in. blooming mill, is evidently some well known plant, though I do not know which. Is this mill only intended to cog down blooms for re-sale ? There is no indication of what the mill is feeding. The blooming mill is followed by some form of transfer, but it is not clear. There is no indication of a hot shear, unless it is the little rectangle just in front of the transfer. If this is so, I do not see where the shear measuring gauge is going to be situated. A few notes on the sketches would have made a big difference.

In Fig. 6, we start off with four stands which are called the blooming mill. Is this a blooming mill with four stands in tandem ? Does it take the ingot right from the soakers, or should Fig. 5 be turned upside down and joined to the bottom of Fig. 6 ? The four stands which are called the blooming mill are followed by five stands of billet rolls. They are all shown as horizontal stands, so that in the absence of any vertical stands there must be some form of twist guides between each of them. Figure 7 is a 28-in. structural mill, with three stands, presumably 2-in. high rolls, reversing rolls, and operating with travelling tables. Could the authors give their opinion of a layout such as this compared with a fixed three-stand mill with fixed tables and skid gear ? Again in this diagram there is no hot shear.

Mr. **Robinson :** With reference to the beam rolls with the large collar, we have tried in a number of cases to design joist rolls with equal diameters of about 36 in., and not to use a collar of about 45-in. dia. when rolling a joist with an 8-in. or a 6-in. flange. We have not, however, evolved a design which will roll a good joist by having all the joists somewhere near the middle of the section. Larger collars and small collar holes are inevitable. Each integral part of a section must be rolled and given the same elongation about a centre-line to keep the average elongation at a similar figure, to avoid bad delivery. It might be possible to work more gradually using about 20 passes, but then the material would be cold. At present these awkward collars are unavoidable.

We aim at 45-in. centres in a cogging mill, because it would give a longer roll life and better results. Drafts would be increased a little with the larger diameter. A dressing of ⅝ in. is removed after one or two weeks of 17,000 tons, and small diameters are soon reached, so that we thought it would be an advantage to have something extra on the 40-in. dia. Many mills are 40-in. but some go up to 50 in., especially in U.S.A., for special sizes.

The drawings of the mills are just layouts with no details at all. Many of these drawings are published in more detail elsewhere. In the blooming mill (Fig. 5) the rectangle which Mr. Craig mentions is a shear. We have only shown this diagram in our paper as a blooming mill illustrating that type of mill. Figure 6 is a special bloomer of the continuous type situated at Gary, U.S.A. This is a blooming mill for the first part, and the material is twisted and turned so that there are nine continuous passes.

Figure 7 shows a 3-high roughing mill, and there are travelling tables for the three sets of rolls on the finishing train. This is common practice in U.S.A., and works very well. We would prefer roller tables and not carriages. The timing however is good and the carriage is always at the rolls when required. Figure 8 is just a type of cross-country mill ; I do not know what size it rolls, but a mill of this type is excellent for 1⅞–4-in. rounds.

Mr. **T. W. Hood** (Samuel Fox and Co., Ltd.) : I fully agree with the authors on the importance of determining the pass design and using this as a major factor when planning a new mill. I wish that this aspect had been developed more fully, for in spite of the value of this paper a better title would be ' Factors in Planning a New Rolling Mill,' as the title and subject matter do not conform. There is, in fact, very little mention of roll design. For example, at the bottom of Table III, which deals with roll speeds for rounds, the authors show that the pass design is oval-round, but they do not explain why they chose that design instead of the alternatives such as oval-square, diamond-square or oval-edge-oval, all of which have been used in recently installed mills. Was it chosen for surface quality, *i.e.*, to avoid wrinkling, or was it to improve accuracy ? How does the number of stands required compare with that necessary for the alternative designs, what guide tackle is involved, and how flexible is this particular design ? I would also suggest that a valuable addition would have been a diagram of the pass layout, starting at the top of the page with the billet size and drawing a family tree showing which passes are used in which stands to obtain the various finished sizes. This is a clear and concise method of showing how it is proposed to use a mill.

When dealing with the size of the mill, the figures given for the limiting angle of contact ignore the effect of speed. From experience of difficulty in entering certain stainless grades in a looping rod mill, I would suggest that the limiting angle of contact is considerably lower at high speed than the figures quoted and is nearer the graph given by Puppe and Stauber,* and by Trinks,* where with smooth rolls the angle falls to about 12° above a speed of 600–800 ft./min.

The Ekelund formula has been accepted for a number of years as being a useful method of working out approximate roll load and torque. In the translation† of Ekelund's

*J. Puppe and G. Stauber, " Walzwerkswesen," vol. 2, p. 123 : 1934, Düsseldorf, Verlag Stahleisen m.b.H. ; W. Trinks, " Roll Pass Design," vol. 1, p. 66 : 1933, Cleveland, Ohio, Penton Publishing Co.

†S. Ekelund, *Steel*, 1933, vol. 93, Aug. 21, pp. 27–29 ; Aug. 28, pp. 44–46 ; Sept. 4, pp. 38–41 ; Sept. 11, pp. 32–44 ; Sept. 18, pp. 29–32 ; Sept. 25, pp. 71–74 ; Oct. 2, pp. 45–48.

paper it is stated that the values for yield stress were obtained mainly by calculation using the formula and the roll-load measurements of Puppe. Thus, in comparing the formula with the results obtained by Puppe, the authors have checked not so much the formula as whether Ekelund's calculations were correctly carried out. Furthermore, some more recent and presumably more accurate figures against which the formula could better be checked have been published.* It is also somewhat surprising that there is no mention of any more recent formula, such as that by Orowan and Pascoe†.

In the Ekelund formula the value obtained for the yield stress, *i.e.*, the last bracket of the formula, can lead to considerable error, particularly with some of the more highly alloyed steels. In fairness, however, this formula was presumably not designed for steels with high chromium content, such as stainless steels.

On the question of torque, the accepted method is to work from curves of h.p.hr./ton plotted against elongation for the appropriate product and type of mill. However, as such curves are not generally available, a resort to the method outlined in the paper is justified. When calculating lever arm, the slide rule referred to assumes a value of 0·5 of the projected contact length. This gives a reasonable average value, for Orowan and Pascoe† give a curve showing a range of 0·4–0·6 and *The Ball Bearing Journal** shows 0·4–0·5. It must then be remembered that there are two rolls to be driven. In Table V the lever arm is shown to equal the projected contact length only because it has been assumed that one roll is driven instead of two.

The mill layouts in the paper have been mentioned by an earlier speaker in this discussion, but I would add the comment that they represent types suitable for very high output, with little flexibility, and so are not applicable for the production of alloy and special steels.

When dealing with the designation of the size of a mill, the authors correctly state that in plate mills the size is usually indicated by the roll barrel length. I would add that this also applies to wide strip mills. I am not sure that the widely used method of designating the size of other types of mill by the pinion centres is the best method, nor do I believe it to be quite so widespread as is generally believed. To take a very obvious example, it certainly does not apply to blooming-slabbing mills with twin motor drive, for with this kind of mill there are no pinions. Nor does it apply to high-lift blooming-slabbing mills with pinion drive because there the pinion centres are frequently several inches greater than the maximum designed roll diameter, so as to reduce the spindle angularity when the top roll is fully lifted. Consequently, with such mills the roll diameter does not, in practice, range between ± 5% of the pinion centres. To use the diameter of new rolls is a more useful indication of mill size.

I hope that this stimulating paper will prove to be the first of several on this very important subject.

Mr. **Robinson :** We have purposely dealt with points in connection with roll design which we thought would be of assistance to the engineer.

We are using the oval-round-oval design of reduction increasingly at our works and cutting out square passes, as overfills in these passes are dangerous and give laps, the round passes being much safer (*see* the various methods of reduction given in answer to Mr. Thomson on p. 352). I understand that the oval-edge-oval is quite a sound method for special steels but is less flexible than the other methods and the average reductions are smaller.

Mr. Hood is correct about the angle of bite. Speed of roll does of course affect the grip of the rolls and we have found by experiment that at 360 ft./min. rough rolls require an angle 4° less and smooth rolls 10° less. Adequate reduction is obtainable even with these reduced angles, *viz.*, 30° on rough rolls and 15° on smooth.

With reference to pinion diameters it is not wise to run with roll centres of larger diameter owing to the spindles, etc., being out of line, thus causing heavy wear on boxes and spindles. I think that it is sensible to describe a mill according to the pinions.

Mr. **W. Udall** (Brightside Foundry and Engineering Co., Ltd.) : The authors are right to stress the desirability of close co-operation between the roll designer and the plant builder in the early stages.

I understand that the oval-edge-oval system of pass progression is technically sound but very inflexible in use and I would welcome the author's comments regarding the effect of material analysis, mill speed, surface condition of roll, and roll size on this system of pass progression, as I understand that these variable factors have to be held to a degree of consistency hardly practicable outside a laboratory.

In the rolling of squares would the authors adopt a system of square-diamond-square if the mill to be used is of the continuous type ? I believe that this system of pass progression is the best when the dimension across the sides of the square is important. If, however, the dimension across the corners of the square and the cross-sectional area of the billet (as with shell blanks and tube billets) are important, the square-diamond-square system may not be the best. What is the authors' opinion about the use of alternate squares and rectangles in box-pass progression with a continuous mill ? If it was a cross-country type, would their opinion be the same ?

In a continuous type of mill the production of flats is not difficult but in many continuous mills edging or vertical stands do not exist. That being the case, would the authors recommend diagonal rolling or tongue-and-groove rolling for the production of sharp-cornered flats on the supposition that the mill chocks can be held against the diagonal thrust and that the thrust collars are of generous size to keep the roll position consistent ?

Mr. **Robinson :** Mr. Udall mentions the oval-edge-oval system of reduction which we have never used in its entirety, owing to its limited reduction and its inflexibility when used in a schedule where a large number of sizes is required. All factors which affect the spread of the stock, such as roll quality, surface condition, temperature of stock, roll size, etc., must be kept within extremely close limits. The oval-round-oval is the logical development of this method and is quite sound.

With regard to the rolling of squares we would suggest a square-diamond-square for a continuous type mill, and there is no reason why the squares should not be rolled sufficiently accurately to fulfil all requirements with respect to tolerances across the sides or corners. The alternate use of squares and rectangles is not to be recommended because the dimensions of the box passes increase in width owing to wear. We prefer the square-diamond-square method also in a cross-country mill.

With regard to diagonal rolling with strong thrust collars we would strongly advise against this method. Experience shows that the collars only support the end thrust fully at one particular thickness ; with any variation in thickness the thrust is not supported correctly. We would recommend tongue and groove here.

Mr. **G. A. Phipps** (Guest Keen and Nettlefolds (South Wales) Ltd.) : Last week the Training Committee of the British Iron and Steel Federation deplored the fact

* *The Ball Bearing Journal*, 1947, No. 1, pp. 13–22 ; *Ibid.*, 1950, No. 1, pp. 3–19.

† E. Orowan and K. J. Pascoe, Spec. Rep. No. 34, pp. 124–146 : 1946, London, The Iron and Steel Institute.

that it was not possible at any university or technical college to study rolling-mill technique in all its aspects, and recommended that this be remedied. If such a course is introduced, its success will depend on the co-operation of practical mill managers and roll designers.

In Table II figures are given for a mill rolling 60,000 tons in roughly 1239 hr. or 48·43 tons/hr., which means about 200,000 tons/year. I would refer to squares in particular, because they are put down as though they were going to be rolled in this mill. I do not think that they would be rolled in a continuous mill, but tonnages are given from 20 up to 400. There is only one of 400, but there are two of over 200, and so on. It would never be economical to put squares in such a mill, because although it is a split-up of 60,000 tons our knowledge of the trade is such that squares tend to be static, even though the mill output rises on rounds and other sections. There would never be large enough tonnages to run a continuous mill economically on squares.

On p. 187 the authors say : "Only in bar and rod mills can it be said that pass designs are more or less standardized." But other methods are used.

On p. 190, under the heading 'Layout of Mill,' the authors say : "The layout must also provide the following : (i) A sufficiently large area for steel stocks of 1½ weeks' supply for the mill." Our experience is that 1½ weeks is nowhere near enough ; it should be nearer 2½ or even 3, because the present tendency is to roll such a wide range of quality and size that billet stocks are rolled very rapidly. In the same paragraph of the paper, the authors go on to say : "(ii) A suitable area for furnaces of ample heating capacity, say, 10% greater than the best production size of the mill." That could mean the highest tonnage size in the mill, or alternatively the highest actual size, the highest tonnage produced by the mill ; on furnaces for such mills I think that it is better to take a good average tonnage of the mill requirements. Assuming that that is about 40 tons/hr., the furnace should be designed for 40 tons to give the maximum efficiency, and it should be capable of being boosted by at least 25% for odd sizes in the mill.

In the third requirement of the layout as given by the authors in the same paragraph, they refer to "a stocking area large enough to stock a week's output of the mill in case of emergency." This should be multiplied by 2, or perhaps 2½, because we find that with a mill giving an average of 3500 tons our stock is about 7000. That is often due to cancellations and to hold-ups by customers who cannot take immediate delivery, and to export difficulties, which provide quite a problem to-day.

Mr. **Robinson :** I agree with Mr. Phipps's remarks about rolling squares, and about bar and rod mills.

Economically, and for reasons of space, it is best to keep as small stocks as possible.

With regard to the furnace, Mr. Phipps does what we do, in a different way. He says that the furnace should be capable of an overload of 25%. We have for 60 tons/hr. two furnaces of 35 tons/hr., so that we have a capacity for 70 tons as against 60, and can do 35 tons in one furnace. These tonnages may not be 25% over requirements, but they seem capable of dealing with all demands.

Mr. **R. Stewartson** (The United Steel Companies Ltd.) : I feel that hot rolling research along three main lines is indicated. The first and perhaps most obvious is to establish reliable methods of roll load calculation for simple sections such as squares, rounds, and ovals. My colleagues and I have found the Ekelund formula fairly simple to use but not very accurate ; in particular, compared with a series of actual load measurements in wide-plate mills it gave results sometimes as much as 50%, and on the average 25%, low. Formulæ based on Orowan's theory showed better agreement on flat products but there seems to be no reliable means of calculating loads for shaped bars and sections.

Secondly, it would be most useful to investigate the respective virtues of different types of pass design for bars, such as diamond-square, oval-square, and oval-edge, particularly in relation to speed of reduction and elimination of rolling defects. Recent experience leads me to believe that these two features are somewhat incompatible and that to minimize defects it is of prime importance to take light reductions. By 'light' I do not mean so much so that the bars are difficult to guide and hold up in the pass, but much lighter than the 35% or more which is common in rod mills.

Thirdly, no method of calculating working diameter is satisfactory and some research on forward slip is desirable. The methods in Fig. 4 of the paper give different results. For example, in the case of a 10-in. mill rolling a 1-in. square, then, assuming a roll gap of $\frac{1}{16}$in. and sharp corners to simplify calculations, the first method gives a working diameter of 9·214 in. ; the second gives 9·354 in., and the third method 9·355 in. A difference of this order could lead to difficulty in pass calculations for continuous mills, particularly in geared trains where no adjustment of individual stand speed can easily be made, so that to obtain satisfactory conditions roll diameters may have to be modified.

Referring to the illustrations of typical mill layouts, Fig. 6 is similar to a continuous blooming and billet mill installed in the U.S.A., in 1910, and rolling ingots of 23–24 in. square down to 8-in. square blooms in the first nine stands, which are spaced so that the ingot is only in one of them at a time. It is very inflexible, since these first stands can only take a single size of ingot, and deliver one size of bloom. For the same output, one or possibly two modern single-stand reversing blooming mills could replace the first nine stands with advantage. In the 18-in. train, gear drives are shown, and although there are modern mills with this form of drive, there is a trend towards horizontal-vertical stands with individual drives, both in the U.K. and the U.S.A.

The 28-in. 3-high structural mill of Fig. 7 is of a type rarely seen in the U.K. British practice seems to favour 2-high section mills for this application as the roll costs are low, and diagonal rolling can be practised without the need for cross collars, etc. Travelling tilting tables are said to need rather heavy maintenance and this may also be a contributory factor in the preference for 2-high heavy-section mills.

Mr. **Robinson :** We agree that more research is needed on hot rolling. That must come, and then we shall probably find out the truth about some of these differences of opinion. Mr. Stewartson suggests that the Gary mill (Fig. 6) might have one or two ordinary type of bloomers if built again, but that mill was built very many years ago for a special job. In regard to the twist not taking so much horse-power as might be thought, the Lackawanna Works of the Bethlehem Steel Co., who substituted verticals, have assured us that by doing away with the twist on the roll drives they saved 30% of the total power required.

CORRESPONDENCE

Mr. **N. D. Thomson** (The United Steel Companies Ltd.) wrote : Some people may feel a sense of disappointment in the paper after reading the imposing title, but it is nevertheless a good practical paper by two experienced men and will be generally welcomed as a first step towards roll designers delivering papers on pass design regularly to the Iron and Steel Institute.

Up to now, when one has wanted to study the subject of pass design, it has been practically impossible to find

suitable works of reference, and a series of papers given by competent pass designers such as the two authors would be most welcome. When studying such a subject as mechanical engineering, one has an almost infinite variety of text books to choose from, but not so on the subject of roll design, and this fact impedes progress.

I should very much like the authors' opinion about the relative merits of oval-square, oval-round, and diamond-square methods of reduction for use in bar and rod mills. The oval-square method has been criticized from the point of view of crinkling. Could the authors substantiate this in any way from their own experience ? They have chosen oval-round reduction for their new bar mill in spite of the smaller reduction obtainable this way.

It would be a brave man who would say that the rolling of sections had at the moment been reduced to a science rather than an art, but I should like the opinion of the authors as to whether the simpler designs such as those mentioned above can be reduced to a science by means of, say, graphs of stock size plotted against spread factor for various roll diameters, steel qualities, temperatures, and speeds.

The method of obtaining the pitch line, as quoted by the authors on p. 190, seems to give reasonably good results, but I believe it is generally recognized that it is inaccurate for sections which have a re-entrant ; *e.g.*, if the section shown in Fig. 3 of the paper had the additional portion shaded, as in Fig. A, then by inspection one would expect the pitch line to move downwards. (The Lennox method is based on the equivalent-area principle). By following the steps outlined by the authors, however, the pitch line would in fact move up in this example, thus showing the inaccuracy of the method. For sections where no re-entrant is present then the method appears to be accurate, if one assumes that the equivalent-area principle itself is valid.

Are not Tables IV and V rather misleading in arriving at the conclusion that the Mogiljanski slide rule gives results sufficiently over-estimated to give a safety factor ? The lever arm column in these two Tables is exactly double what it should be as the lever arm is equal to the torque divided by twice the load, since the torque is shared by two rolls. This then shows the lever arm to be almost exactly half the projected contact length which indeed is the factor used in the Mogiljanski slide rule. The last two columns therefore merely prove that the Mogiljanski slide rule uses a lever arm equal to 0·5 of the projected contact length. The authors quote factual figures of the lever arm varying from 0·5 and 0·877 of the projected contact length in the Timken tests and from 0·36 to 0·42 in the diamond passes. Thus the slide rule gives low values of torque for such applications as are similar to the box passes and high values for applications such as the diamond-pass design. Since the pass designs which the authors have considered have been closer to diamond designs than the box-pass ones, their conclusion that the Mogiljanski slide rule over-estimates is probably accurate, but it is not a true generalization.

Mr. **Robinson** wrote in reply : The following gives the relative merits of the various reduction methods :

Square-oval-square—This is the quickest method of reducing a billet to small sizes and thoroughly removing scale. It is, however, also the most dangerous from the point of view of seam formation because of the non-uniform distribution of pressure in the oval passes and the large amount of spreading allowed to the lateral surfaces.

These surfaces, initially straight, tend in the oval passes to ' concertina ' and the scale trapped in the corrugations thus formed is further rolled in when the oval passes through the following square.

Diamond-square-diamond—Not so quick in reduction but because of total enclosure and simultaneous working of all four sides this series prevents the formation of pressure seams and even helps to remove existing ones. It does not, however, remove primary scale so effectively as the previous series.

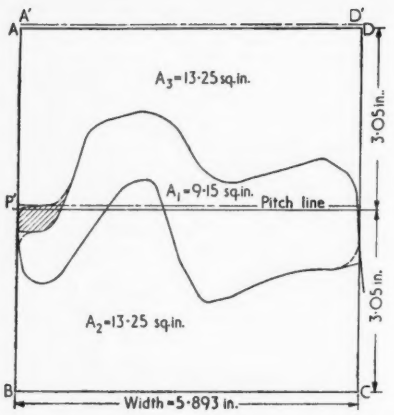


Fig. A—An inaccuracy in the Lennox method

It is essential that the various passes be completely filled for efficient working. Diamond passes permit only little adjustment to feed larger squares. Much adjustment leads to underfilling with the chance of forming seams in the top and bottom corners of the following square pass.

To cover effectively the range of sizes required more passes both diamond and square are called for with smaller steppings in dimensions.

Round-oval-round—This is a logical development from the slow-reducing oval-oval series and though not reducing quite so fast as the diamond-square method has the distinct advantage of retaining convex surfaces around the bar and so completely eliminating any possibilities of pressure-seam formation.

Scale is effectively removed and torn surfaces are prevented.

Further references to this series (and the others) are made by Brayshaw.*

The design of some of the simpler shapes can be assisted by graphs and nomograms dealing with spread, working diameters, areas, speeds, temperatures, steel quality, roll quality, etc., but then one would say this is roll design.

There may be cases where the Lennox method would need correcting where re-entrants are concerned, but we would say the method is suitable in the majority of cases.

We use the Mogiljanski rule with confidence after a long trial period.

Mr. **W. P. Sneddon** (British Timken Ltd.) wrote : The paper is misleading in its title in so far as at one stage it is confined to roll-pass design and then opens out into mill design. The authors have perhaps overstretched a confined subject ; the paper might have been enhanced if they had told us more of the roll designer's art and less about the variety of rolling mills in which sections referred to in the paper could be rolled.

It is regrettable that the two important parts of any roll, *i.e.*, the wobbler end and the roll neck, are not even referred to. What are the authors' views on the best type of roll neck fillets and wobbler ends for section mills ?

I suppose there are as many different designs of roll passes for a required section or shape as there are roll pass designers. This is understandable when one considers the number of variables which can cover the production of a standard section in, say, two or three different steelworks of similar tonnage capacity. It is fairly

* E. E. Brayshaw, *Blast Furn. Steel Plant*, 1949, vol. 37, pp. 821–830.

safe to assume that no two production units will arrive at the finished roll section required in exactly the same way. Nevertheless there must be one best way of producing a standard section to which all production units could more closely align themselves.

I should like the authors to explain to us how they develop the various sections from the ingot stage, *i.e.*, from the initial drawing of the section which I presume is necessary to ensure that in the first place it can be rolled successfully, to the finished final template which must allow for contraction of section after rolling. Will they state what contraction allowance they do recommend in, say, the final pass of a 12 in. × 3½ in. channel rolled to ordinary structural-steel specification?

Since roll-pass design is the real subject of the paper, I would welcome replies to these points and queries:

(1) The best ways of working the metal in the various passes, including squeezing, spreading, and bending.

(2) Is it better to spread the heaviest reductions over the various passes as early as possible, the finishing pass being the exception, correction to trueness of shape being the most important requirement in the final pass?

(3) The need to stress that all sides of the piece being rolled be thoroughly worked in the correct sequence.

(4) The avoidance of deep grooves, when possible, which necessarily weaken the rolls.

(5) The need to ensure as far as possible that all passes are balanced so as to limit or avoid end thrust.

(6) In all box passes the work will not enter the rolls if it is larger in all directions than the pass. However, in diagonal passes the piece can be larger than the pass in any direction provided that the section is properly proportioned to avoid overfills.

(7) Obviously the thin parts of the section cool more rapidly than the heavier parts and consequently all thin parts should, I presume, be formed in the later passes.

(8) In all sections requiring deep-groove passes, the peripheral speed of the top and bottom of the grooves should be most carefully considered. It is obvious that the part of the roll having the greatest diameter elongates the pass more rapidly than the part having the smallest diameter, thereby creating a tendency in the pass to twist and curl on leaving the rolls. Is this best avoided by using rolls of slightly different diameter or by raising or lowering the centre mass from the pass line, or by reducing the amount of reduction on the part that elongates more rapidly?

(9) The correct proportioning of draught on various parts of section being rolled to avoid distortion.

(10) All steels do not work alike. What can be done with O.H. steel cannot always be done with Bessemer steel and *vice versa*. Will the authors give us their experience?

Mr. **Robinson** wrote: It is unfortunate that the title of our paper was misinterpreted. The authors' aim was not a description of various aspects of roll-pass design but an attempt to indicate some of those mill peculiarities which reduce roll-pass efficiency and how these may be eliminated when a mill is in the design stage with subsequent benefit to the conversion costs.

Mr. Sneddon's suggestion that there must be one best way of producing a given standard section is rather idealistic, since the pass design for any one mill is determined by the size, power, and layout of that mill. Obviously, as no two mills are exactly alike the 'best' roll-pass designs will vary accordingly.

Space limitations preclude any explanation of the development of various sections from ingot, bloom, or billet. The necessary requisites are an intimate knowledge of the mill or mills involved together with a sound experience of the behaviour of the stock on its passage between rolls. Only general rules could thus be given.

The question of contraction allowance is a matter of tolerances and finishing temperature. In section rolling the usual allowance is 1½% of linear dimensions and on this basis the width of the finishing pass for a 12 in. × 3½ in. channel should be 12 $\frac{3}{16}$ in.

Wear of the side walls of the pass would cause a gradual increase in this width which, because of the very slight conicity or taper in the side walls, could not be recovered by normal roll dressing. The cold-finished section would very soon reach top tolerance and the rolls would have to be discarded though still of usable diameters.

It is, therefore, the usual practice to turn new rolls with the finishing pass width such that in the first rolling the width (or height, as the engineer understands it) of the cold-finished section will be about $\frac{1}{16}$ in. under the nominal dimension.

For the 12-in. channel under consideration the finishing pass width with new rolls should be made 12$\frac{1}{8}$ in.

The flange lengths do not suffer in this respect and the usual contraction allowance is made on these parts.

Although, as has been said, roll-pass design was not intended as the subject of the paper, Mr. Sneddon's queries are worth an answer.

(1) The best method of working depends on the size, power, and layout of the mill, the nature of the material to be worked and its final use always being kept in mind.

(2) It is better practice to use the heaviest and most unequal reductions in the earlier passes where, because of higher temperature and greater plasticity, the stock more easily adjusts itself to the stresses arising from the inequality of reduction on the various parts. Some inequality of reduction can rarely, if ever, be completely eliminated since the initial cross-section is rectangular and the required finished shape may be anything.

(3) This is essential if sound material is required.

(4) Deep grooves present entry and delivery difficulties and are avoided if possible.

(5) Balancing of lateral draft is the usual practice. Where complete balance cannot be attained, as, for instance, in the rolling of flat-bottom rails, interlocking collars must be used.

(6) Box passes have the advantage of simplicity, easy entry and delivery, and they remove scale efficiently. In these passes only two sides receive direct working. The two vertical sides are subject to tension which must be counteracted by direct work in the next pass or by suppression of spread by the side walls of the pass. Neglect of this may lead to badly cracked surfaces.

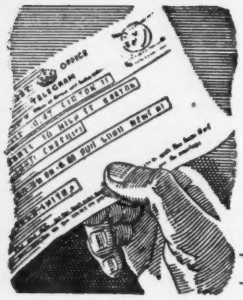
(7) This is a matter of the required finished section. With beams and channels the calibration of the passes is based on the web drafts. The other parts of the section are drafted in proportion.

Some sections have thin parts which cannot receive direct draft in the later passes of a schedule and these must be formed in the earlier passes. Examples of such are the fingers of the cleats of piling sections, continuous rail fish plates, etc.

(8) Where a section requires deep grooves the differences in peripheral speeds must be balanced by increased upsetting at the bottom of the groove.

(9) This question really requires a paper in itself. It has been proved that within the pass there is an internal flow of material from a heavily drafted part to an adjacent lightly drafted part. Correct proportioning and distribution of draft should keep this flow to the minimum consistent with full development of the required section.

(10) As stated there are differences in the reaction to work of different steels. These differences are not so great as may be thought during the earlier passes when the temperatures may be above 1000°C. In the latter passes adjustments may be necessary and these are made by the roller during the process.



NEWS

ANNOUNCEMENTS AND NEWS OF SCIENCE AND INDUSTRY

THE IRON AND STEEL INSTITUTE

Autumn General Meeting, 1954

The **Autumn General Meeting** of The Iron and Steel Institute will be held in London on **Wednesday and Thursday, 24th and 25th November, 1954.** Details of the programme will be given in a later issue of the *Journal*.

Staff

The following promotions have been made with effect from 1st July, 1954:

Mr. C. R. Harman, Assistant Editor since 1947, has been appointed Technical Editor. Mr. H. F. Cleere becomes Production Editor and Mrs. E. S. Fairhurst Assistant Editor.

Miss L. E. Field, who has been responsible for the office organization on the advertisement side since 1947, has been appointed Advertisement Manager.

Mr. E. R. Mort continues as Managing Editor, in charge of all Institute publications.

NEWS OF MEMBERS

▶ Mr. M. BIRKHEAD has left the United Steel Companies, Ltd., to become Chief Metallurgist and Welding Superintendent to W. P. Butterfield Ltd., Shipley, Yorks.

▶ Mr. G. BURNS has left the Admiralty Materials Laboratory to join the Department of Aeronautical and Engineering Research, London.

▶ Mr. C. W. GUNNEE has left Barrow Steelworks to take up the appointment of Chief Fuel Engineer at the Redbourn works of Richard Thomas and Baldwins Ltd.

▶ Mr. T. W. HORWOOD has left B.I.S.R.A. and is now a metallurgist with the Aluminium Development Association.

▶ Mr. H. P. HUGHES has been appointed Works Manager of the British Electro Metallurgical Co., a Division of Union Carbide Ltd.

▶ Mr. R. F. JENNINGS has left B.I.S.R.A. to join Huntington, Heberlein and Co.

▶ Professor E. JIMENO of the University of Madrid has been awarded the degree of Doctor in Engineering honoris causa of the Engineering College of Hanover, Germany.

▶ Mr. N. B. RUTHERFORD has left the British Non-Ferrous Metals Research Association to join Cam Gears Ltd., Luton.

▶ Mr. J. SAVAGE, Head of the Physics Department of B.I.S.R.A. at Battersea, has been promoted Superintendent.

▶ Mr. L. H. WALKER has left T.I. Aluminium Ltd. to join the Metals Division of Imperial Chemical Industries Ltd., Birmingham.

▶ Mr. JOSEPH WALTON, Joint Managing Director of Thos. W. Ward Ltd., completed 50 years' service with the Company on 14th March, 1954.

▶ Mr. J. F. WHITFIELD has left B. Thornton Ltd., to take up the appointment of Chief Engineer to the Round Oak Steel Works Ltd.

Obituary

Mr. J. C. W. HUMFREY, of Launceston, Devon, on 20th March, 1954.

Mr. E. F. LAW, an Honorary Vice-President of The Iron and Steel Institute, on 22nd May, 1954.

Mr. A. E. LEEK, of Workington, Cumberland, on 4th May, 1954.

Mr. C. M. STEIN, founder of Stein et Roubaix, Paris.

Mr. JOSEPH F. WOSCHITZ, Assistant Superintendent of Research and Development, Inland Steel Co., Chicago, U.S.A., on 12th December, 1953.

CONTRIBUTORS TO THE JOURNAL

P. T. Moore, Ph.D., D.I.C.—Boiler Plant Manager with Imperial Chemical Industries Ltd. (Billingham Division).

P. T. Moore

Dr. Moore was born in 1928. He was educated at Whitgift Middle School, Croydon, and at the Imperial College of Science and Technology, graduating with 2nd Class Honours in Metallurgy in 1948. In the same year he was made an A.R.S.M. He remained at Imperial College, carrying out a programme of research sponsored by B.I.S.R.A., and in 1951 he was awarded the D.I.C. and the degree of Ph.D. of the University of London. He joined the Billingham Division of I.C.I. as a Metallurgical Investigator in the same year, and took up his present appointment in the following year.

E. Maud McBriar, B.Sc.—Petrologist in the Research and Development Department of the United Steel Companies, Ltd.

Miss McBriar received her technical education at Melbourne University, Australia, graduating in 1945. Her association with the iron and steel industry began as an undergraduate in the employ of the Broken Hill Pty. Co., Ltd. She then spent six years in the study of mining and economic geology, before taking up her present appointment in 1952. She is now engaged in research on sinter problems.

In Australia Miss McBriar assisted in the production of the first regular review of the mining industry, "*The Australian Mineral Industry.*" She is an Associate Member of the Australasian Institute of Mining and Metallurgy.

B. G. Baldwin, Ph.D., A.R.I.C., D.I.C.—Research Assistant at the Imperial College of Science and Technology.

Dr. Baldwin was born in 1926 and was educated at the Brighton, Hove and Sussex Grammar School, and at Brighton Technical College, graduating with honours in Chemistry in 1948. In the same year he joined the Blast-Furnace Laboratory at Imperial College, and in 1953 he was awarded the degree of Ph.D. for a thesis on the reduction of iron ores. He has recently been engaged in studying the kinetics of reactions between solids that occur during sintering and in the blast-furnace.

BRITISH IRON AND STEEL RESEARCH ASSOCIATON

Forty-Second Steelmaking Conference

The Forty-Second Steelmaking Conference was held at Ashorne Hill on 12th–13th May, 1954. The Chairman of the Conference was Dr. T. P. Colclough, O.B.E., and Mr. R. W. Evans was Vice-Chairman.

The Conference was divided into two sessions: "*Oxygen in Steelmaking*," and "*Operational Research in Steelmaking*." During the first session Mr. D. J. O. Brandt reviewed post-war developments in the use of oxygen, and discussed future trends. Dr. A. J. Kesterton spoke on the removal of carbon by means of a roof-mounted oxygen jet, and Mr. C. A. Reed described the de-siliconization of ladles with an oxygen jet. The speeding-up of steelmaking operations when using oxygen was stressed, and the possibility of reduced costs of oxygen was discussed.

Mr. R. Solt opened the second session with a talk on the application of operational research methods in steelworks, in particular an investigation of the supply of materials to an open-hearth shop. This description was based on detailed studies carried out by the B.I.S.R.A. Operational Research Station, the results of which revealed the general principles of the efficient supply of materials to the furnaces. Mr. R. T. Eddison gave a brief review of the growth of operational research methods in industry, outlining several ways in which these were already being used or were likely to be used to advantage in the open-hearth melting shop.

Formation of Bainite

A new 16-mm. sound film, "*The Formation of Bainite*," has recently been produced by the British Iron and Steel Research Association. The film illustrates the work carried out by Dr. T. Ko and Dr. S. A. Cottrell for B.I.S.R.A. at the University of Birmingham (the full results of this work were published in the *Journal* for November, 1952, pp. 307–313), and shows diagrammatically the essential structures that form during the heat-treatment of steel. Time-lapse photography is used to show the actual formation of martensite and bainite in steel specimens at high temperatures, under a 'hot-stage' microscope. This is the first successful technique developed for filming the formation of bainite.

Copies of the film are available, free of charge, from the Association.

NEWS OF SCIENCE AND INDUSTRY

Production Exhibition and Conference

A Production Exhibition and Conference will be held by the Institution of Production Engineers at Olympia, London, on 7th–14th July, 1954. One of the ten sessions into which the Conference is divided is on "*Scientific Research and the Changing Pattern of British Industry*." Two papers will be presented: "*Materials for Gas Turbines*," by Dr. H. Sutton, C.B.E., and "*The Gas Turbine and the Production Engineer*," by Dr. Alexander King, C.B.E.

World Power Conference

The Rt. Hon. Lord Citrine, P.C., K.B.E., Chairman of the British Electricity Authority, has been appointed by H.M. Government to represent the Government as Official Delegate at the Brazilian Sectional Meeting of the World Power Conference, to be held on 25th July–10th August, 1954. Sir John Hacking, Vice-Chairman of the British National Committee of the Conference, will represent the Committee as Official Delegate.

The Annual Report of the Conference for 1953 has been published, and copies are obtainable from the offices of the British National Committee, World Power Conference, 201–2 Grand Buildings, Trafalgar Square, London, W.C.2 (price 1*s.* 6*d.*, post free).

Congress of Mining and Metal Industries

The Société de l'Industrie Minérale celebrates its Centenary in 1955. To commemorate the occasion the Société is organizing a Congress of Mining and Metal Industries, to be held in Paris on 20th June–3rd July, 1955. The metallurgical programme for the Congress will include sessions on blast-furnace design and materials, steelmaking processes, rolling mills, and hot extrusion. Visits will be made to French industrial centres. An International Exhibition of Mining and Metal Industries will also be held in conjunction with the Congress. Further details of the programme may be obtained from the General Secretary of the Congress, 60 boulevard Saint-Michel, Paris 6e.

British Instrument Industries Exhibition

The 1955 British Instrument Industries' Exhibition will be held at Earls Court, London, on 28th June—9th July, 1955. Details of the programme have not yet been announced, but the Exhibition will cover all spheres of instrumentation in pure and applied science. Exhibits will include temperature, pressure, and flow controllers, navigation equipment, medical instruments, industrial photography, and all instruments used in scientific research.

Research Fellowship in Metallurgy

Through the generosity of the English Steel Corporation Ltd., Thomas Firth and John Brown Ltd., and Firth Vickers Ltd., the University of Sheffield has recently established the J. H. Andrew Research Fellowship in Metallurgy. The Senate of the University has now made the first award of this Fellowship to Mr. R. G. Ward, a research student in the Department of Metallurgy at Cambridge University, working under the direction of Dr. T. P. Hoar. It is hoped that Mr. Ward may take up his tenure of the Fellowship on 1st July, 1954.

Institute of Mining and Metallurgy

The Gold Medal of the Institution of Mining and Metallurgy has been awarded to Mr. Essington Lewis, C.H., President of the Fifth Empire Mining and Metallurgical Congress, in recognition of his long and distinguished services to the mining and metallurgical industries of Australia.

Institute of Physics

At the Annual General Meeting of the Institute of Physics, held on 18th May, 1954, Sir John Cockroft, Director of the Atomic Energy Research Establishment

at Harwell and Chairman of the Defence Research Policy Committee, was elected President. Mr. G. R. Noakes was elected a Vice-President, and Dr. S. Whitehead and Dr. B. P. Dudding were re-elected Hon. Treasurer and Hon. Secretary respectively. The two new Ordinary Members of the Board elected were Dr. K. A. G. Mendelssohn and Mr. H. P. Rooksby.

British Standards

The British Standards Institution has recently issued B.S. 1991: Part 1: 1954, "*Letter Symbols, Signs and Abbreviations.*" Two earlier Standards (B.S. 560: 1934—"*Engineering Symbols and Abbreviations,*" and B.S. 813: 1938—"*Chemical Symbols and Abbreviations*") have been combined to form B.S. 1991, especially in so far as they relate to the more fundamental quantities of common interest to physicists, chemists, and engineers. It is obtainable from the British Standards Institution, British Standards House, 2 Park Street, London, W.1 (price 6*s.*). Subsequent Parts of this Standard will be the results of specialized work based on the foundations laid in Part 1.

Technical Course in Leoben

At a technical course, held by the Technische-Wissenschaftlicher Verein Eisenhütte Österreich at Leoben, on 28th–29th May, 1954, Lieut.-Col. A. Post, Joint Assistant Secretary of The Iron and Steel Institute, gave a lecture on "*New Developments in the Iron and Steel Industry in Great Britain.*"

Films on Finishing Processes in the Steel Industry

A series of filmstrips on the finishing processes in the iron and steel industry have recently been produced by the British Iron and Steel Federation. It consists of 13 films under the following titles: "*From Ingot to Billet*"; "*Section, Bar and Rod Rolling*"; "*Rolling Narrow Strip*"; "*Plate Rolling*"; "*From Slab to Sheet*"; "*Tinplate—Hot Dip Tinning*"; "*Tinplate—Electrolytic Tinning*"; "*Wire Drawing*"; "*Bright Steel Bars*"; "*Tube Making*"; "*Heavy Forging*"; "*Bolts and Nuts.*" Illustrated lecture notes containing a descriptive commentary on the processes have also been prepared to accompany each filmstrip.

Copies of the filmstrips are available free of charge to member companies of the British Iron and Steel Federation. They are obtainable from The Training Department, Windsor House, 46 Victoria Street, London, S.W.1. Outside organizations may obtain copies, price 10*s.*, from G.B. Equipments Ltd., Aintree Road, Perivale, Greenford, Middlesex.

Flame Radiation Research

A new experimental station of the Flame Radiation Research Joint Committee has recently been completed at the Royal Netherlands Blast Furnaces and Steelworks Ltd., Ymuiden, and was inaugurated on 28th April, 1954. The Committee has now published an illustrated booklet, giving a full description of the new station and of the equipment that it will house.

Steel Pipes for Water, Gas, Sewage, and Air

Stewarts and Lloyds Ltd. have recently published an up-to-date edition of their book, "*Steel Pipes for Water, Gas, Sewage and Air.*" This comprehensive catalogue deals with the manufacture of steel pipes, internal and external protections and protections for transport, the selection of joints, and the laying of pipes. A general description of 'S & L' steel pipes is given, together with details of the 'specials' manufactured by the Company. There are sections on the flow of water and gas in pipes, and the book, which is fully illustrated, includes data on properties, dimensions, and weights of pipes, etc., set out in tabular form.

DIARY

4th–10th July—BRAZILIAN ASSOCIATION OF CHEMISTRY—11th Brazilian Chemical Congress—Sao Paulo, Brazil.

6th–9th July—INTERNATIONAL UNION OF PURE AND APPLIED PHYSICS—Commission on Electron Microscopy—London.

7th–10th July—INSTITUTE OF PHYSICS (Non-Destructive Testing Group)—Summer Meeting—Chancellor's Hall, University of Birmingham.

7th–14th July—INSTITUTION OF PRODUCTION ENGINEERS—Production Exhibition and Conference—National Hall, Olympia, London.

13th–17th July—UNIVERSITY OF BRISTOL (H. H. Wills Physical Laboratory) (in co-operation with the International Union of Pure and Applied Physics and the Institute of Physics)—Conference on Defects in Crystalline Solids—The University, Bristol.

19th–20th July—UNIVERSITY OF BIRMINGHAM (Department of Metallurgy)—Conference on "*Mechanical Effects of Dislocations in Crystals*"—Birmingham.

21st–28th July—INTERNATIONAL UNION OF CRYSTALLOGRAPHY—Third General Assembly and International Congress—Paris.

25th July–10th Aug.—Brazilian Sectional Meeting of the World Power Conference—Petropolis, Brazil.

TRANSLATION SERVICE

(The previous announcement was made in the June, 1954, issue of the *Journal*, p. 260.)

TRANSLATIONS AVAILABLE

No. 487 (German). K. MÖHL: "The Sampling of Ores and Slags during Ironmaking." (*Archiv für das Eisenhüttenwesen*, 1954, vol. 25, Jan./Feb., pp. 33–37).

No. 488 (Russian). M. A. SOLNTZEN, L. M. CHEMODANOV, and A. A. KUZIN: "Making Steel Castings from Steel Produced in a Small Converter." (*Liteinoe Proizvodstvo*, 1953, No. 5, pp. 8–11).

TRANSLATIONS IN COURSE OF PREPARATION

(German). C. BRUCHHAUSEN: "Lining of Hot-Metal Mixers." (*Stahl und Eisen*, 1953, vol. 73, Nov. 5, pp. 1453–1457).

(German). "The Lining of Mixers": (*A*) K. MAYER, F. GAREIS, S. KIENOW, H. KNÜPPEL, and G. TRÖMEL: "The Lining of an 800-Ton Mixer with Dolomite Bricks." (*Stahl und Eisen*, 1953, vol. 73, Nov. 5, pp. 1457–1462). (*B*) K. MAYER and H. KNÜPPEL: "The Lining of an 800-Ton Mixer with Chemically Bonded Magnesite Bricks." (*Stahl und Eisen*, 1953, vol. 73, Nov. 5, pp. 1463–1464).

(French). P. CATTIER, C. DUBOIS, J. BLETON, and P. BASTIEN: "Contribution to the Study of Banded Structures in Forging Steel. Influence of the Migration of Carbon and Thermal Treatment on Minor Segregation." (*Revue de Métallurgie*, 1953, Apr.).

CHARGES FOR COPIES OF TRANSLATIONS—The charge for translations is £1 for the first copy and 10*s.* for each additional copy of the same translation. Requests should be accompanied by a remittance. These translations are not available on loan from the Joint Library.

ABSTRACTS OF CURRENT LITERATURE *and* BOOK NOTICES

IRON AND STEEL MANUFACTURE AND RELATED SUBJECTS

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MINERAL RESOURCES

Symposium on the Iron Deposits of the World. (19th International Geological Congress, Algiers, 1952, vols. I, II and III). These three volumes, edited by F. Blondel and L. Marvier, contain the papers presented at the 19th International Geological Congress held at Algiers in 1952. Volume I is devoted to African, American, and Asian deposits, and Volume II to the countries of Europe with a small section on New Caledonia, and New Zealand, whilst Volume III consists entirely of maps. The papers in the first volume are :

The World Resources of Iron Ores. F. G. Percival. (XVII–XXXI).

Documentation on the Iron in French Equatorial Africa. (1–3).

The Iron Deposits of French West Africa. F. Blondel. (5–34).

Study of the Iron Deposits of Algeria. G. Bétier, L. Glangeaud, M. Jouhaud, L. Duplan, J. Hilly, G. Dubourdieu, and F. Juston. (35–77).

Iron Deposits of Angola. H. Vieira. (79–82).

The Iron Ores of the Belgian Congo. C. Ancion and L. Cahen. (83–100).

The Iron Deposits of Eritrea. L. Usoni. (101–118).

The Iron Deposits of Ethiopia. L. Usoni. (119–125).

Iron Ores in Kenya Colony. M. W. Pulfrey. (127–130).

Notes on the Iron Ores of Madagascar. (131–133).

The Iron Deposits of Morocco (Spanish Zone). D. A. Marin. (135–144).

The Iron Deposits of Morocco (French Zone). J. Agard, J. Destombes, R. Naudet, and W. van Leckwijck. (145–161).

Notes on the Iron Ore Deposits of Nigeria. (163).

Iron Ore Deposits in Northern Rhodesia. W. H. Reeve. (165–170).

Iron Ores in Southern Rhodesia. R. Tyndale-Biscoe. (171–174).

Iron Ore Deposits in Sierra Leone. N. W. Wilson. (175–182).

The Iron Deposits of Somaliland. L. Usoni. (183–185).

Iron Ores in the Anglo-Egyptian Sudan. G. Andrew. (187–189).

Iron Ore in Swaziland. H. J. R. Way. (191–192).

The Titanium-Bearing Iron Occurrences of the Njombe District, South-West Tanganyika. J. R. Harpum. (193–208).

The Metallurgy of the Liganga Ores. [Tanganyika]. J. H. Harris. (208–209).

The Iron Ore Deposits in Tunisia. C. Gottis. (211–220).

Iron Ores of the Uganda Protectorate. (221–222).

Iron Ore in the Union of South Africa and in South-West Africa. G. K. Joubert. (233–263).

Iron Ore Deposits of the Argentine Republic. (267–284).

The Iron Ore Deposits of Brazil. (285–310) :

Geographic Distribution. L. Jacques de Moraes. (285).

Origin of the Brazilian Iron Ores. J. van N. Door II, P. W. Guild, and A. L. M. Barbosa. (286–304).

The Iron Industry in Brazil. L. Jacques de Moraes. (304–306).

Iron Ores in Canada. T. L. Tanton. (311–352).

The Iron Ore Deposits in Chili. E. Nef. (353–359).

The Iron Deposits in Colombia. (361–368).

Notes on the Iron Ore Deposits in Ecuador. G. Toro Teran. (369).

Memorandum on Iron Deposits in the United States of America. C. E. Dutton. (371–411).

Iron Ore Deposits in the Territories and Overseas Possessions of the United States and on Certain Islands Under Its Jurisdiction. P. L. Killeen, Martha S. Carr, and D. E. Flint. (413–427).

Indications of Iron Ore in the Republic of Guatemala. (429).

Iron in French Guiana. B. Choubert. (431–434).

The Iron Ore Deposits of Mexico and Their Geology. J. Gonzalez Reyna. (435–453).

Iron in Peru. (455–459).

The Iron Ores of the Province of Duarte, Dominica. R. Zoppis. (461–471).

Indications of Iron Ore at Saint-Pierre and Miquelon. F. Blondel. (473).

Some Notes about the Occurrence of Iron Deposits in Surinam. H. Schols. (475).

Geology, Paragenesis, and Reserves of the Iron Deposits of Imataca in Venezuela. E. Rubio, C. M. Bellizzia, and R. Laforest. (477–498).

The Iron Deposits of Cambodia. F. Blondel. (499).

The Iron Ores of India. M. S. Krishnan. (503–532).

Note on the Iron Deposits of Iran. M. Mahmoudi. (533–535).

Iron Ore Deposits in Japan. T. Mitsuchi. (537–560).

Indications of Iron Ore at Laos. F. Blondel. (561).

Note on the Indications of Iron Ore of Lebanon. (563).

Notes on the Iron Ore Deposits of the Federation of Malaya. F. J. Ingham. (565–579).

Note on Iron Ore in Pakistan. (581).

The Geology of Iron Ore Deposits of the Philippines. L. Santos-Ynigo. (583–608).

Note on the Indications of Iron Ore in Syria. L. Dubertret. (609).

Memorandum on Iron Deposits of Thailand. (611–618).

The Iron Deposits of Turkey. E. N. Egaran and E. Göksu. (619–630).

The Iron Deposits of Vietnam. F. Blondel. (631–638).

The papers in the second volume are :

The Iron Ore Deposits of Germany (2–38) :

Total Deposits. J. Hesemann. (2–3).

The Mesozoic Iron Ores of Lower Saxony. O. Seitz, K. Hoffmann, F. Preul, and H. Kolbe. (3–8).

The Iron Ores of North Rhineland-Westphalia. J. Hesemann. (8–9).

The Iron Ore Deposits of the Harz. J. Hesemann. (10).

The Siegerland Iron Ores. R. Thienhaus and M. Kloess. (11–13).

The Iron Ores of Hesse. H. J. Lippert and M. Teike. (13–15).

The Palaeozoic Iron Ores of Thuringia. H.–R. von Gaertner. (15–16).

The Iron Ores of Württemberg. H. Wild. (17–18).

The Iron Ores of Baden. K. Sauer. (18–20).

The Iron Ores of Bavaria. H. Gudden, P. Schmidt-Thomé, and H. Tillmann. (20–23).

The Geochemistry of Iron. C.–W. Correns. (23–27).

The Behaviour of Iron in Exposed Areas. J.–H. Hellmers. (27).

Mineralogical Investigations on Sedementary Iron Ores. C.–W. Correns. (28–30).

Geophysics. W. Wolff. (33–38).

The Iron Ore Deposits of the Österreichische-Alpine Montangeselschaft. A. Kern. (41–73).

The Iron Ores of Belgium. C. Ancion. (75–91).

The Iron Deposits in Spain. A. de Alvarado, M. Pastor Mendevil, and R. Montero Ruiz. (93–116).

The Iron Ores of Finland. V. Marmo. (117–127).

Study of the Iron Deposits of France. F. Cusset, F. de Torcy, and P. Maubeuge. (129–222).

The Iron Ores of Greece. G. Aronis. (223–226).

Iron in Hungary. G. Pantó. (227–246).

Memorandum on Iron in Italy. F. Penta. (247–347).

Study of the Iron Deposits of the Grand Duchy of Luxembourg. M. Lucius. (349–387).

The Iron Ore Resources of Norway. A. O. Poulsen. (389–397).

Note on the Iron Deposits of the Netherlands. (399).

Information on the Iron Ores of Portugal. A. M. de Jesus. (401–404).

The Iron Ore Deposits of Great Britain. (405–471) :

Some Magnetite Ores in Scotland. T. H. Whitehead. (417–422).

Iron Ore Deposits of Furness. K. C. Dunham. (423–427).

The West Cumberland Haematities. F. M. Trotter. (427–431).

Forest of Dean Haematites. F. M. Trotter. (431–434).

Genesis of the West Coast Haematite Deposits. F. M. Trotter and K. C. Dunham. (435–438).

Iron Ores of the Northern Pennines (England). K. C. Dunham. (438–440).

The Jurassic Ironstone Fields of the East Midlands of England. V. Wilson. (441–450).

The Iron Ore of the Weald. F. H. Edmunds. (451).

The History and Future Prospects of Ironstone Mining in North-East Yorkshire. W. Anderson. (451–452).

The Petrology of the British Mesozoic Ironstones and Its Bearing on Problems of Beneficiation. J. H. Taylor, W. Davies, and R. J. M. Dixie. (453–466).

The Nature of Silicates and Carbonates of Iron in the Northampton Sand Ironstone of Central England. E. Cohen. (466–471).

The Iron Deposits of the Sarre District. N. Theobald. (473–476).

The Iron Ores of Sweden. P. Geijer and N. H. Magnusson. (477–499).

The Iron Deposits of Switzerland. H. Fehlmann and F. de Quervain. (501–527).

The Iron Ore Deposits of Yugoslavia. L. Nöth. (529–563).

The Iron Deposits of New Caledonia. P. Routhier. (567–587).

The Iron Ore Resources of New Zealand. H. E. Fyfe. (589–594).

World Deposits of Coal, Iron, Petroleum, and Uranium. W. Hagen. (*Glückauf*, 1954, **90,** Jan. 2, 1–31). The location, distribution and state of development of the main deposits of coal, iron, petroleum, and uranium are outlined.—L. D. H.

Reddened Beds in the Coal Measures of South Lancashire. F. M. Trotter. (*Bull. Geological Survey of Great Britain No.* 5, 1954, 61–80).

The Coal Measures of the Anthraconaia Lenisulcata Zone in the East Midlands Coalfield. R. A. Eden. (*Bull. Geological Survey of Great Britain No.* 5, 1954, 81–104).

The Leigh Creek Coalfield. L. W. Parkin. (*Geological Survey of South Australia Bull.* 31, 1953).

The Statistical Evaluation of the Sampling of Ore Deposits. H. J. de Wijs. (*Z. Erz. Met.*, 1953, **6,** Sept., 348–350). The special conditions characterizing the sampling of ore deposits are shown to yield on approximately logarithmic binomial distribution of ore values. Formulæ for calculating scatter, theoretical mean, and optimum estimated values are given and demonstrated.—E. C.

The Map of Mineral Deposits in the Eastern Alps. O. M. Friedrich. (*Radex Rundschau*, 1953, Aug.–Sept., (7–8), 371–407). A large geological map of the eastern Alps was produced by the author, showing 1400 mineral deposits mostly small and without economic importance. The deposits include some 300 occurrences of various iron ores. (136 references).

Mineralogical Relationships between Deposits of Magnesite and Siderite in the Eastern Alps. H. Meixner. (*Radex Rundschau*, 1953, Aug.–Sept., (7–8), 445–458). A close relationship between the two types of carbonate deposits is postulated.—E. C.

Recent Information on Some Russian Manganiferrous Deposits. A. G. Betekhtine. (*Ann. Mines*, 1953, **142,** (8), 31–51).

New Information on the Geology of the Polounotch Deposit in the Northern Urals. A. Betekhtine. (*Ann. Mines*, 1953, **142,** (8), 36–39).

Oulou-Teliok, New Deposit of Oxide-Carbonate Manganese Ore in Permian Age Deposits of Bachkirie. A. Khabakov. (*Ann. Mines*, 1953, **142,** (8), 39–44).

Manganiferrous Deposits in the Meridional Urals. A. Betekhtine. (*Ann. Mines*, 1953, **142,** (8), 44–45).

The Geochemistry and Mineralogy of Manganese. A. Betekhtine. (*Ann. Mines*, 1953, **142,** (8), 46–49).

The Genetic Types of Manganese Deposit. A. Betekhtine. (*Ann. Mines*, 1953, **142,** (8), 50–51).

Resources for the Chemical Industry in the United States—Wyoming. H. G. Fisk. (*Indust. Eng. Chem.*, 1953, **45,** Nov., 2449–2454). The resources of minerals, petroleum, and natural gas, are surveyed. Deposits of titaniferous magnetite are estimated at 43×10^6 tons, and a process for recovering vanadium, TiO_2, and iron has been prepared. The Sunrise Mine iron ore is an important factor for the western steel industry, and other deposits are known. (80 references).—K. E. J.

Geology and Coal Deposits in Part of the Coos Bay Coal Field, Oregon. D. C. Duncan. (*U.S. Geological Survey Bull.*, 982–B, 1953).

Iron-Ore Deposits of the Iron Mountain District, Washington County, Idaho. J. H. Mackin. (*U.S. Geological Survey Bull.* 982–E, 1953). The iron ore deposits of the district are magnetite and specularite replacements in the marble unit of Permian metamorphic rocks. Reserves available for open-pit mining are 150,000 to 200,000 tons, of which only about 20,000 tons are measured ore.—R. A. R.

Limonite Deposits near Scappoose Columbia County, Oregon. P. E. Hotz. (*U.S. Geological Survey Bull.* 982–C, 1953).

Magnetite Deposit of the Sterling Lake, N.Y.—Ringwood, N.J. Area. P. E. Hotz. (*U.S. Geological Survey Bull.* 982–F, 1953). Most of the iron-bearing material is crystalline magnetite, though in some places small amounts of hematite are intimately associated with it. The grade ranges from about 35 to 68% iron.—R. A. R.

Studies on Suwa Iron Ore (Including Gumma Iron Ore). K. Kikuchi and S. Sasaki. (*Tetsu to Hagane*, 1949, **35,** July, 190–197; Sept., 280–287). [In Japanese]. Details are given of the distribution and formation of the deposits, mineral

constituents, and properties of two high-phosphorus ores. The solubility of phosphorus in citric acid, and the behaviour of the phosphate under heat and reduction were determined for Suwa ore. The ore, after suitable treatment, may be used as a phosphate fertilizer. For this high-phosphorus ore, changes caused by sintering and reduction, and the solubility of phosphorus in citric acid, were studied. (11 references).

Ore. F. G. Percival. (*Lithgow J.*, 1953, **1,** Winter issue, 25–28). The author, in this survey of world iron ore supplies, describes the steps nations are taking to open up new fields and ensure a steady flow of raw material for industry in the future.—L. E. W.

The Iron Sea. J. Pfeiffer. (*Steelways*, 1953, **9,** Dec., 1–5). The geological history of the Lake Superior iron ranges is traced. About one billion years ago sedimentation built up iron bearing strata which were folded by volcanic flows. The deposits were enriched by erosion and the entire region was then covered by new seas during which time further rock layers were formed by sedimentation. A few million years ago the land was again uplifted from the sea, and finally the ore was exposed by retreating glaciers.—L. E. W.

The Mineral Deposits of Morocco and Mauretania. R. Thienhaus. (*Stahl u. Eisen*, 1954, **76,** Jan. 14, 76–82). Papers presented at the 19th International Congress of Geologists held in September 1952 at Algiers are summarized. The importance of the reserves in this region for European industry is discussed.—J. P.

Observations and Some New Ideas on the Mineral Resources of New Caledonia. P. Routhier. (*Echo Mines*, 1953, Sept., 593–597). The mineral deposits of this island are described. Deposits of nickel, cobalt, iron, chromium and manganese have been found.—B. G. B.

ORES—MINING AND TREATMENT

The Iron Mines of France. (*Mét. Constr. Mécan.*, 1953, **85,** Sept., 733–737). A short description of the location, activities and production of the iron ore mines in France, is given.

Fairless Works Ore and Coal Unloaders. L. Naruns. (*Iron Steel Eng.*, 1953, **30,** Dec., 140–146). The author describes the new 15-ton trolley unloaders of the U.S. Steel Corporation's new Fairless Works on the Delaware River. The scheme was put in to deal with rich imported ores from Venezuela.—M. D. J. B.

A New Design of Wagon Tippler. (*Metallurgia*, 1953, **48,** Dec., 299–300). A new fully automatic wagon tippler is described, which is able to handle the 24½-ton standard wagon of the Ministry of Transport but will also deal with smaller wagons down to 8 tons. An important feature is that no clamping or binding mechanism is needed.—B. G. B.

Study on the Economic Efficiency of the Mechanical Concentration of Ores. P. Seyer. (*Rev. Ind. Min.*, 1953, **34,** Nov. 15, 929–956). A theoretical study of the treatment of run-of-mine ore to produce a reject and a simple concentrate is given. The application of this theory to washery control is discussed. Simple formulæ for actual concentrates are given and a statistical study of three washeries reported. An appendix deals with the establishment of quality control charts.—A. G.

The Present State of Grinding Technique. G. Quesnel. (*Genie Civil.*, 1953, **130,** Oct 1, 370–372 ; Oct. 15, 388–391 ; Nov. 1, 405–407). The important characteristics of the product to be ground are discussed and the need for careful sampling is stressed. The three fundamental methods of grinding (crushing between fixed and moving parts, impact pulverization, and tumbling) are outlined and available grinding equipment is reviewed. The triconical Hardinge ball mill has the greatest efficiency with no dead zones. Equipment for sizing the ground material is described, it being advantageous to separate during grinding *e.g.*, by a current of air. Factors determining the choice of grinding technique are dealt with.—A. G.

A Method of Predicting the Performance of Commercial Mills in the Fine Grinding of Brittle Materials. G. L. Fairs. (*Trans. Inst. Min. Met.*, 1953–54, **63,** Part 5, 211–240). A method is described for predicting the performance of a series of commercial grinding mills relative to that of a laboratory impact crusher operating under free crushing conditions. Three brittle substances (limestone, barytes, anhydrite) were examined and the relative mill efficiencies, the gradients of the lines relating net energy input and the new surface produced, were found to be in the same ratio for each. Similarly on the basis of fineness indices assigned to the mills for each test, the ratio of these indices was the same for the series in the case of each material. This means that, given a laboratory test on a unit impact crusher for a new brittle material, the energy/surface ratios and the order of fineness can be predicted therefrom for the other mills in the series. The performance ratios on the basis of the associated energies of the materials concerned were substantially the same as those for the energy/surface relationships. (23 references).—L. E. W.

Some Grinding Tests with Spheres and other Shapes. G. C. Norris. (*Trans. Inst. Min. Met.*, 1954, **63,** Part 5, 197–210). The author describes a series of laboratory tests to determine the relative grinding efficiencies of the following shapes as ball-mill grinding media : Sphere, sphere with six small flat faces, cube, combined cube and octahedron, circular cylinder, and circular disc. On a plant scale the cube and sphere were tested in parallel ball-mills. It is concluded that the nearer the approach in shape of grinding media to a sphere the more efficient is the performance.—L. E. W.

A Practicable Method of Describing and Assessing Grinding Processes and Plants. G. F. Hüttig, W. Ebersold, and H. Sales. (*Radex Rundschau*, 1953, (9–10), Nov., 489–493). A series of functions is proposed on the basis of sieve analyses which assess the progress of pulverization. Quartz sand and talc are used for examples, fragmentation is found to prevail with the former, abrasion dominates with the latter.—E. C.

The Iron and Steel Industry of Australia. C. More. (*Mét. Constr. Mécan.*, 1954, **86,** Jan., 7–9). A short description of the activities of the Port Kembla, Newcastle, and Whyalla plants is given. The development of the iron ore deposits at Cockatoo Island off the N.W. coast of Australia is described. The ore passes through two crushers and is reduced to < 4 in., and the capacity of the plant is two million tons of ore per year.—B. G. B.

Iron Ore Shipments from Cerro Bolivar to Begin Next Month. (*Eng. Min. J.*, 1953, **154,** Dec., 92–94). Ore shipments by the Orinoco Mining Co. will commence in January 1954, at an annual rate of 2×10^6 tons, to reach 5×10^6 tons in 1954 and eventually 10^7 tons. The handling arrangements to deal with this tonnage are described.—K. E. J.

Froth Flotation of Iron Ores—Adsorption of Starch Products and Laurylamine Acetate. N. F. Schulz and S. R. B. Cooke. (*Indust. Eng. Chem.*, 1953, **45,** Dec., 2767–2772). Experiments were made to determine some reasons for the assistance given by starch to the froth flotation of certain minerals. The degree of adsorption was found to depend on the properties of the particular starch, the mineral, and the prevailing physical and chemical conditions, including the presence of other dissolved substances in the liquid phase. (29 references).

Enrichment of Flue Dust by Fluidized Magnetizing, Roasting and Low Intensity Magnetic Separation. M. Beaurain, P. Emery, and M. Pambet. (*Rev. Ind. Min.*, 1953, **34,** Dec. 15, 1077–1087). Laboratory tests on fluidized magnetizing roasting indicate a possible method of treatment and the concentration achievable. An experimental furnace is under construction to develop the process, which should prove economic for flue dust enrichment.—A. G.

Magnetic Separators for Extraction. The Relative Advantages and Disadvantages of Disc and Crossed Band Machines. P. Saurel. (*Rev. Ind. Min.*, 1953, **34,** Dec. 15, 1096–1108). The characteristics of belt separators (with a magnet below the belt) and disc separators (in which ore particles with a certain velocity are deflected) are compared and the rôles of speed and size grading discussed. Belt separators are less selective but more robust and need less attention.—A. G.

Concentration of Iron Ores in Metropolitan France. M. Beaurain and L. Coche. (*Rev. Ind. Min.*, 1953, **34,** Dec. 15, 1069–1076). Possible processes of ore enrichment (apart from reduction to metallic iron) are considered. The Ore Section of IRSID has made a number of trials on several French ores to determine the optimum enrichment at different size gradings. The approach to this optimum in industrial plant is considered.—A. G.

Beneficiation of Iron Ores: Recent Developments in Northamptonshire Practice. A. Stirling. (*West of Scotland Iron Steel Inst., Paper No.* 462, Jan. 22, 1954 ; *Iron Coal Trades Rev.*, 1954, **168,** Jan. 29, 273–277). The beneficiation of iron ores is discussed with particular reference to current practice and recent developments in the Northamptonshire district. The nature of the ore and the method of winning are described, and details are given of ore preparation, sintering, handling

of sticky ore fines, briquetting, and pelletizing at the Corby works of Stewarts and Lloyds Ltd.—G. F.

Report on Taconite. (*Steelways*, 1953, **9,** Oct., 1–5). Considerable progress has been made by the mining companies in developing commercial methods of concentrating taconite. Since 1948 new plants have been erected with a total capacity of over 1,500,000 tons and two large plants with a combined capacity of 20 million tons are being built. The hardness of taconite has necessitated the development of new drilling methods such as the use of jet-piercers. The rock from the drilling and blasting is crushed and ground, and then passed through magnetic separators. The magnetic concentrate is pelletized with powdered coal in a balling drum, or with coke in a kiln or on a moving grate. No commercially successful concentration process has been developed for non-magnetic taconite, but flotation and conversion to magnetic form by controlled heating seem promising methods.—L. E. W.

Sampling Ores and Slags in Ironmaking. K. Möhl. (*Arch. Eisenhüttenwesen*, 1954, **25,** Jan.-Feb., 33–38 ; *Iron Steel Inst. Translation Series No.* 487, 1954). The methods and precautions to be taken to ensure that samples are representative of the average composition of ore and slags are discussed generally.—J. P.

The Determination of the Particle Size of Industrial Pulverized Materials by the Pipette Method. A. H. M. Andreasen. (*Chim. et Ind.*, 1953, **70,** Nov., 863–867). The author shows that the fineness of a pulverized material is not sufficiently defined by the average grain size, and that it is necessary to find the distribution of the different grain sizes in the given sample in order to forecast the behaviour of the material. The principle of a sedimentation method, which allows the evaluation of the amount of substance in suspension and hence the particle size, is explained. The apparatus and technique used are described.—B. G. B.

Blast-Furnace Burden Preparation Using Lorraine Minnette Ores. P. Thierry. (*Mét. Constr. Mécan.*, 1953, **85,** July, 543–545 ; Aug., 603–605). A large number of the blast-furnace plants using Minnette ores are situated very close to the mine and it is difficult to insert an ore preparation plant between the furnace and mine. The quality of the iron produced from a furnace charged with uncrushed Minnette tends to be unsatisfactory as both silicon and sulphur analyses become erratic. The crushing and sizing of Minnette are discussed. Charging the crushed ore into the furnace in layers of different sizes has been adopted but is not completely satisfactory. The application of the Dwight Lloyd sintering process to this ore is discussed.—B. G. B.

More Iron from Minnesota's Lean Ores. A. W. Mathews. (*Eng. Min. J.*, 1953, **154,** Oct., 88–90). A survey is given of the ore and concentrates production in Minnesota, which totalled 19·6 million tons in 1952. Various plants, large and small, are used for the treatments of direct shipment, dry screening, washing, scrubbing, jigging, heavy-density separation, Humphreys spirals, sintering, and drying.

The Mineralogy of Blast Furnace Sinter. H. M. Kraner. (*Min. Eng.*, 1953, **5,** Nov., 1114–1117). An account is given of the mineral constituents and petrography of sinters, and the reactions occurring during sintering, with particular reference to fayalite formation and the effects of incorporating various proportions of lime. Sinter is a heterogeneous product of relatively incomplete reactions. (25 references).—K. E. J.

The Nature of Ironstone Sinster. E. M. McBriar, W. Johnson, K. W. Andrews, and W. Davies. (*J. Iron Steel Inst.*, 1954, **177,** July, 316–323). [This issue].

The Formation and Decomposition of Fayalite ($2FeO.SiO_2$). B. G. Baldwin. (*J. Iron Steel Inst.*, 1954, **177,** July, 312–316). [This issue].

The "Slide Separator", a New Magnetic Separator for Mineral Dressing. Landthaler. (*Z. Erz. Met.*, 1953, **6,** July, 266–268). A new magnetic separator is described and some performance data are quoted. The machine has no moving parts. The dry ore powder moves under gravity from a feeder down an inclined plate towards a magnetic field, being separated from the magnet by another inclined slide plate. After sliding along the plate under the influence of the magnet, particles fall into one of three collecting chutes. Freedom from mechanical wear, high capacity, and great efficiency are claimed.—E. C.

Some Observations on the Application of Microstructure, Yield Strength of Sinter and Sieve Analysis of Each Size of Sinter after Shatter Test. C. Yamada, H. Takano, K. Ukita, and M. Okumura. (*Tetsu to Hagane*, 1949, **35,** Oct., 325–328). [In Japanese]. It is possible to regulate the moisture content of sinter, mixing ratio, and sintering time, by examination of production sinter. Decrease in the lower size limit from 15 to 10 mm. increases sinter yield by 13·6% and strength by 10·5%. Smaller sizes of sinter suffer less degradation by shatter.—K. E. J.

FUEL—PREPARATION, PROPERTIES, AND USES

Fuel and Economics. R. J. Sarjant. (*Inst. Vitreous Enamellers Ltd., Bulletin*, 1953, **4,** June). The author discusses economic aspects in the selection and use of fuel for the enamelling industry. Conditions for efficient combustion of coal are given. (13 references).—R. P.

Fuel and Power Saving in a Large Ironworks. T. M. Niven. (*Fuel Econ. Rev.*, 1954, **32,** 51–59). An account is given of changes and modifications to boiler plant (three Lancashire boilers), steam and condensate mains, forge and other process furnaces, electrical plant, and lighting which, in the last three years, have led to important savings in fuel and power at the works of Mechans, Ltd., Glasgow. This company has large steel plate fabricating shops.—R. A. R.

Boiler Availability. (*Brit. Coal Utilisation Res. Assoc., Quarterly Gaz.*, 1953, (18), 6–11). The instruments and techniques developed by one of B.C.U.R.A.'s research teams for the study of the corrosion and fouling of external heating surfaces in large water-tube boilers are briefly reviewed. Sulphur trioxide in the flue gases acts as a low-melting cement bonding together ash and coke particles, and also condenses as sulphuric acid on metal surfaces. The rate of deposit collection diminishes with time and with increasing surface temperature. The composition of the deposit is not affected by such factors. The incidence of deposit formation is influenced by the type of coal, that containing more than 0·3% chlorine giving most trouble. The peak rate of acid condensation and maximum corrosion occurs between 40 and 80° F. below the dew-point. Pulverized-fuel boilers are less prone to deposit and corrosion troubles.—L. E. W.

Smoke Control. (*Iron Age*, 1953, **172,** Nov. 19, 166–169). A set of nozzles placed inside a coal-fired furnace for distribution of secondary air over the fuel bed and operated by a photo-electric sensing system has been successfully used for smoke control. Hunting of the system is prevented by a timing sequence for the blower.—A. M. F.

Fundamentals of Smoke Emission. (*Brit. Coal Utilisation Res. Assoc., Quarterly Gaz.*, 1953, (18), 2–5). A description is given of current researches by B.C.U.R.A. on the study of phenomena concerned with the release and combustion of volatiles. The experimental approach is being conducted along three main lines : (1) Studies of the effects of the method and rate of heating of coal particles, coal type, mineral and other impurities, and chemical pretreatment on the disengagement of volatiles ; (2) the determination of the optimum conditions for ignition of volatile–air mixtures by hot refractory and metal surfaces ; and (3) a study of carbonaceous materials from diffusion flames of burning volatiles. In each case a diagram of the apparatus is given and the results obtained are indicated.—L. E. W.

Combustion Theory and Practice. W. P. Jensen. (*Chem. Eng.*, 1953, **60,** June, 190–194, 221). The physical-chemical nature of the combustion mechanism is discussed. After considering the problems of ignition and flame propagation, the functions of combustion equipment and the design of burners for pulverized fuel, oil and gas are dealt with.—A. G.

Fuels—Choice and Handling. J. C. McCabe. (*Chem. Eng.*, 1953, **60,** June, 186–189). After considering the price and availability of different fuels, future trends and the comparative properties of major fuels are discussed. New sources of fuels include atomic breeder piles, underground electro-carbonization, and low-temperature carbonization.—A. G.

The Thermal Spectrum in Heat Technology. (*Chem. Eng.*, 1953, **60,** June, 177–184). A three-colour folded chart gives data on the production of heat and cold, the heat content of metals, refractories, and insulating materials, heat transfer media, and typical process temperatures.—A. G.

Electric Heating Methods. C. H. Chilton. (*Chem. Eng.*, 1953, **60,** June, 195–199). A classification is given of the available methods of electric heating and the transfer of heat and energy relationships are described. The various methods

such as infra-red, induction, arc, and dielectric heating are then considered individually.—A. G.

Tubular Process Furnaces. C. Bliss. (*Chem. Eng.*, 1953, **60,** June, 208–212). Tubular furnaces are used for heating or vaporization of process fluids and heat transfer media, and for supplying endothermic heat for chemical processes. They employ either natural or forced circulation. The effects of tube length and location and economic considerations governing the choice and design of equipment are discussed.—A. G.

Media for Heat Transport. J. J. Carberry. (*Chem. Eng.*, 1953, **60,** June, 225–228). The use of the heat transfer coefficient as a function of pumping energy for evaluating transport media is discussed. Liquid media are superior to gas or vapour, giving better surface temperature uniformity and closer temperature control. Liquid phase heat transfer and media for various temperature ranges are discussed.—A. G.

Advances in Heat Transfer. C. F. Bonilla. (*Chem. Eng.*, 1953, **60,** June, 228–232). Empirical methods of design are being augmented by recent developments in theoretical knowledge such as electrical analogues and new unsteady state procedures for measuring thermal conductivity.—A. G.

Newer Types of Metallic Recuperators: Recent Installations. H. Weineck. (*Iron Steel*, 1953, **26,** Dec., 557–560; 1954, **27,** Jan., 23–25). After a general introduction on the use of recuperators, the author describes some of the newer types of metallic recuperators and air heaters, and discusses some of the problems encountered in their construction. Recuperators of special cast metal and of steel are considered, and the 'turbo' air preheater is described. Problems associated with very dirty gases are also mentioned.—G. F.

Development and Application of Steel-Tube Recuperators in the Iron and Steel Industry. F. C. Evans. (*Iron Coal Trades Rev.*, 1954, **168,** Jan. 22, 213–218; Jan. 29, 253–238). After discussing the possible fuel savings brought about by preheating the combustion air, the author describes the design of recuperators with special reference to the development of the steel-tube recuperator. Designs used in the iron and steel industry for use with hot dust-laden gases are next discussed, and finally the advantages of combined convection and radiation types are outlined.—G. F.

Trends in Heat Exchangers. J. C. Smith. (*Chem. Eng.*, **60,** June, 232–238). Air cooled units and extended surface exchangers have come into wide use and the present trend is away from straight tube exchangers to spiral or plate exchangers and other non-tubular designs. Improvements in the design and construction of the various types of exchanger are outlined.—A. G.

How to Approach the Problem of the Reactivity of Combustible Materials. H. Guerin. (*Chim. et Ind.*, 1953, **70,** Nov., 875–885). After defining reactivity, the relation between the efficiency and productivity of a combustion unit and the reactivity of the fuel to oxygen, carbon dioxide, and steam are discussed. Recent work on the kinetics of the combustion process is described in relation to the laboratory determination of absolute reactivity. Errors in the extrapolation of laboratory results to industrial combustion units are considered.

Burners of the Free Air Type. Szczeniowski. (*Centre Doc. Sidér, Circ. Inform. Tech.*, 1952, (11), 1573–1578). Free air burners comprise those used for drying out runners and casting ladles. They have the following characteristics in common: (*a*) Combustion in relatively low temperature surroundings; (*b*) uncontrolled combustion without blown air; and (*c*) variable pressure and volume of gas. The major requirement of such burners is stability rather than high thermal efficiency. Various burner designs are discussed.—A. G.

The Microscopical Study of Coal. V. Hevia Rodriguez. (*Inst. Nac. Carbon Bol. Inf.*, 1953, (9), May, 5–34). [In Spanish]. Numerous micrographs with descriptions of coals from Spain, France, and England are given with an extensive bibliography.—F. R. H.

Chemical Structure and Properties of Coal. I—Elementary Composition and Density. F. W. van Krevelen and H. A. G. Chermin. (*Fuel*, 1954, **33,** Jan., 79–87). A relationship between structure and specific gravity is developed by means of which the number of rings per carbon atom and the fraction of aromatic carbon can be calculated. These quantities are calculated for several vitrinites which were considered representative of the coalification series.—B. G. B.

Chemical Structure and Properties of Coal. II—Reflectance. F. J. Huntjens and D. W. van Krevelen. (*Fuel*, 1954, **33,** Jan., 88–103). A close study of the reflectance of coal as a function of the degree of coalification has been made and the results obtained are discussed in relation to those obtained by other workers.—B. G. B.

Some Aspects of Coal Pyrolysis. Sir Charles Ellis. (*Inst. Gas. Eng. Comm., Publication No.* 436, Nov. 24–25, 1953). Successive changes occurring in coal during heating to temperatures up to 3000° C. are discussed. The following stages in the process are considered: (1) Up to 300° C., coal as such; (2) 300–550° C., decomposition to semi-coke with evolution of volatile matter plus gases; (3) about 550–1000° C., transformation of semi-coke to coke and further emission of gas; and (4) over 1000° to 3000° C., increasing order in the lattice with the approach to graphitization.—V. G.

Considerations on the Activity of Mineral Fuels and Its Determination—The Crucible Method and the Results Obtained. R. F. Rapado. (*Inst. Nac. Carbon Bol. Inf.*, 1953, (7), Jan., 24–29). [In Spanish]. The author discusses the importance of the reactivity of combustibles in the operation of furnaces and describes a crucible test method for its determination.—F. R. H.

A Practical Method for the Determination of the Net Calorific Value of Coals. O. Jenne and E. Schwarz-Bergkampf. (*Radex Rundschau*, 1953, July, (6), 36–39). Customary methods of computing the net from the gross calorific value are outlined and a new method is described. This method, using differential values, is claimed to yield reasonably accurate results with slide rule calculation.—E. C.

The Cleaning of Small Coal. L. W. Needham. (*Year Book Coke Oven Man. Assoc.*, 1953, 308–339). This paper deals with the cleaning of coal below 0·5 in. and the purification of fines less than 1 mm. Froth flotation is regarded as effective for cleaning. The moisture content of small coal is best controlled by basket-type centrifuges and that of fines by filters.—R. P.

Coal Preparation. T. Todd. (*Year Book Coke Oven Man. Assoc.*, 1953, 273–294). The paper considers the production of clean coal, and blending and crushing. Washability data are given and the control of solids in suspension is considered. Froth flotation gives efficient separation of coal from shale but the ash content of the product is high. Ash and sulphur in the coal can be controlled by varying the amount of frothing agent used.—R. P.

Wet Cleaning at the Tralee Preparation Plant. P. Gillie. (*Min. Eng.*, 1953, **5,** Nov., 1104–1107). For cleaning Pocohontas coal, which contains both high and intermediate gravity material, a system comprising roll crushers, a Chance cone, Diester concentrator tables, and Bird filters is used for the entire mine product.—K. E. J.

The Settling Process of Coal Preparation and the Projection Cleaning Process. D. Rühl. (*Forsch. Ingenieurwesens*, 1953, **19,** *VDI–Forschungsheft* 438). A dry cleaning process, in which dirt is separated from coal by projecting it across a rising air stream, is described. It is claimed to be superior to other dry cleaning methods and nearly as effective as wet cleaning.—H. R. M.

Sieving with Heated Screens. M. Zagury. (*Rev. Ind. Min.*, 1953, **34,** Dec. 15, 1088–1095). An historical account of heated sieving development in Germany and America is given. The process was adopted in France in 1948 for screening coke fines produced when coking Lorraine coals. Limiting factors are the balling tendency of fines and the high cost of electricity. The former may be overcome by the addition of 0·2% oil to lower surface tension. Rapid development of the process is predicted.—A. G.

The Oiling of Coal: Six Years' Experience at Stanton. H. Horsley. (*Brit. Steelmaker*, 1954, **20,** Jan., 14–17, 21). Since 1947, standard coke-oven practice at Stanton Ironworks Co. Ltd. has included an oil addition of ½ gal. /ton of coal, resulting in a 5% increase in output due to the more stable bulk density and thus greater uniformity in coal charged. The practical experience gained and the equipment used are described, and the advantages and disadvantages of the system are analysed. The addition provides a simple method of controlling flexibility of output and, in conjunction with crushers, offers improvement of coke quality from sized coal without loss of tonnage.—G. F.

Froth Flotation of Coal Fines: Some Debatable Features. W. Lowes. (*Iron Coal Trades Rev.*, 1954, **168,** Jan. 22, 209–212). Some of the more debatable features connected with the treatment of coal fines by froth flotation are discussed, taking as an example a washery to treat 10 tons/hr. of fines,

with a water storage of 100,000 gal., a circulation of 3,000 gal./min., and maintaining water conditions varying from 0 to 20% solids. The operation of such a plant is described and the economics of the process are discussed.—G. F.

Coke Works Construction at Fishburn. N. Watson. (*Gas World—Coking Section*, 1953, **43**, Dec. 5, 107–109). A detailed description is given of the layout and construction of the new carbonization plant being constructed at Fishburn, Co. Durham. The coke-ovens are in two batteries, each of 25 ovens, and are of Woodall-Duckam Becker underjet regenerative pattern, arranged for rich gas firing with provision for producer gas firing.—B. C. W.

Carbonization of Blends of Coal to Produce Metallurgical Coke. H. Bardgett. (*Inst. Fuel, Advance Copy*, Feb 23, 1954). The results of experiments on the carbonization of blends of Durham and Northumberland coals in Woodall-Duckham intermittent vertical chambers indicate to what extent it maybe possible to conserve the limited resources of the best coking coals.—R. A. R.

Mechanical Engineering Aspects of Coke Works Practice. L. S. Freebury. (*Year Book Coke Oven Man. Assoc.*, 1953, 235–272). This is a review of mechanical handling devices and coke-oven machinery, including those of the by-product plant. Expenditure is taken into consideration.—R. P.

Developments in the Carbonization of Coal. W. I. Jones. (*Year Book Coke Oven Man. Assoc.*, 1953, 140–150). A review of recent trends in carbonization research, including gas purification and by-products is presented. Future progress in coke production will depend on more fundamental work on the problems of coke formation, and on the development of new carbonization processes.—R. P.

Instrumentation in Coal and Coke Handling. A. Linford. (*Coke Gas*, 1953, **15**, Oct., 378–383). The use of measuring instruments and automatic controllers in coal and coke handling is discussed, with particular reference to continuous weighing. Counterbalancing machines are described and the application of pneumatic devices such as are already used in the measurement and control of flow, temperature, and pressure is discussed. The author considers that there is considerable scope for the application of pneumatic equipment to the control of dry materials.—B. C. W.

The Utilization of the Sensible Heat of the Coke-Oven Gas in the First Gas-Cooling Stage of a Coke-Oven Plant. W. Schroeder. (*Glückauf*, 1953, **89**, Nov. 21, 1187–1188). A plant is described which utilizes the heat of the coke-oven gas by circulating the heated cooling water from the first gas-cooling stage. Economies effected and lines of further development are indicated.—L. D. H.

Materials Handling at Steelworks Coke Ovens. S. K. Dean and H. J. Burgess. (*Coke Gas*, 1953, **15**, Oct., 363–370 ; Nov., 415–420). To control coke quality it is necessary to blend coals, and a detailed description is given of bunker blending and the Robins-Messiter bedding system with particular emphasis on the methods used in handling the coal. The transfer of coke from the ovens to the storage areas of the blast-furnace plant is described together with the handling of the iron ore and the charging of both materials into the blast-furnace.—B. C. W.

Preliminary Study of the Effects of Atmospheric Oxidation on the Yields of Primary Carbonization Products of Certain Australian Coals. C. E. Marshall and A. Draycott. (*Fuel*, 1954, **33**, Jan., 26–41). Bituminous coal from two seams in New South Wales have been examined as to the effects of slow oxidation at normal temperatures. Both the low and high volatile samples exhibited progressive variations in coke, gas, tar, ammonia, and liquor yields.—B. G. B.

Some New Carbonization Processes Under Development and Their Relation to Established Practice. D. T. Barritt and T. Kennaway. (*Inst. Fuel and Coke-Oven Managers' Assoc. Preprint*, Jan. 12, 1954). The development of the coke oven up to the present day is traced and it is shown how each improvement in method and design has widened the range of coals which can be carbonized. The inherent limitations of coke ovens are defined. Details of the following processes under development are given : (1) National Fuels process ; (2) Brennstoff-Technik process ; and (3) Baumco process. The basic theory is outlined in each case.—R. A. R.

Pressure Drop in Pipes. M. Steffes. (*Rev. Tech. Luxembourg.*, 1953 **45**, Oct.-Dec., 269–271). A new mathematical treatment for the calculation of the pressure drop in pipes is explained. An example of the use of the method for the calculation of the pressure drop in pipes carrying coke-oven gas is given.—B. G. B.

Electro-Detarrers for Coke Oven Plants. K. W. Francombe. (*Year Book Coke Oven Man. Assoc.*, 1953, 340–354). The author summarizes the characteristics of coke-oven electro-detarrers. Their basic principles and design are outlined and some operating difficulties and faults are pointed out, together with remedies.—R. P.

Steelworks Tar. De Hedouville. (*Centre Doc. Sidér, Circ. Inform. Tech.*, 1952, (12), 1741–1749). Of the many physical and chemical measurements on tars, the only standarized test is that of Redwood viscosity at 30° C. The main characteristics of tars are described and typical properties presented in tabular form. Methods of measuring these properties are discussed.—A. G.

Composition of Coal Tars. D. McNeil and G. A. Vaughan. (*Inst. Gas. Eng. Publication No.* 438, Nov. 24–25, 1953). The development of a scheme of analysis for coal tars is described. Some additional qualitative information on the chemical composition of coal tar pitch and the results of more detailed studies on the chemical nature of tar acids and tar bases are given.—V. G.

Testing the Quality of Steelworks' Tar. Å. Rosengren. (*Arch. Eisenhüttenwesen*, 1954, **25**, Jan.-Feb., 11–18). The standard gravity, (the specific gravity of a tar which has been distilled until the residue has a standard viscosity at a standard temperature) is a good guide to the general chemical character of a tar. Distillation analyses should be reported in the form of continuous distillation diagrams and not as the relative proportions of individual fractions. The viscosity of tar for satisfactory ramming of dolomite linings should be about 100 centistokes ; tar should be characterized by a working temperature at which it has this viscosity. This temperature can be determined from viscosity at ordinary temperatures with the aid of Walther's temperature-viscosity diagram. The usefulness of the softening point of the pitch content of the tar is questionable. On the other hand, the phenol content and the elementary analysis appear to be more important. The coke residue should be determined by a method in which coke formation proceeds slowly. Surface tension appears to play a part in the consolidation of tar-dolomite and the density of a bottom should therefore depend on the surface tension.—J. P.

The Coke Screening Plants III/IV of the Nordstern Coking Plant, as an Example of a Modern Coke Preparation Plant. W. Hürter. (*Glückauf*, 1954, **90**, Jan. 2, 58–61). The design and construction of this plant, rebuilt after war damage, are described, and operating details are given.—L. D. H.

The Factors Causing the Formation of Fissures in Coke. E. M. Taits. (*Doklady Akademii Nauk S.S.S.R.*, 1953, **93**, (6), 1025–1027). [In Russian]. The mechanism of the formation of fissures in coke which are caused by the development of internal stresses appearing as a result of forces counteracting the process of shrinkage is discussed. Internal stresses (σ) appearing in coke and producing fissures are determined by two parameters *i.e.*, The gradient of shrinage (g) and the cohesive force between two adjacent layers (N), The parameter g is determined by the dynamics of shrinkage of the coking material, the latter being dependent on the absolute value of shrinkage and the rate of heating the coking mixture. The parameter N is determined by the coking properties of the coal, *i.e.*, by its viscosity in the plastic state, and depends on particle size, contents of mineral admixtures, degree of compression, and some other factors.—V. G.

Some Legal Aspects of Pollution: With Particular Regard to Effluents. R. M. Hornsby. (*Year Book Coke Oven Man. Assoc.*, 1953, 151–164). This paper gives a history of laws regulating pollution and examines the various aspects of pollution. The work of the River Boards is referred to.—R. P.

The Composition and Treatment of Washery and Coke Works Effluents. G. R. Nellist. (*Year Book Coke Oven Man. Assoc.*, 1953, 165–184). This paper deals with the causes and effects of pollution, methods of filtration, settling tanks, and the recovery of phenols and ammonia. Limiting concentrations of substances harmful to fish are considered. Biological filtration is stated to be efficient for gasworks liquors and coke works effluents. Indirect final cooling of the gas is recommended for cutting down the volume of naphthalene water. (20 references).—R. P.

River Pollution. D. E. Cunningworth and E. R. Forlin. (*Year Book Coke Oven Man. Assoc.*, 1953, 295–307). The

authors summarize the current position of the pollution laws and suggest means of overcoming pollution. Limiting concentrations of substances toxic to fish are given and possible chemicals reactions of coke-oven liquors are considered. (30 references).—R. P.

Pollution Control Can Be Realistic. J. E. Kinney. (*Iron Steel Eng.*, 1953, **30,** Nov., 91–94). This article describes the work done by the Ohio River Valley Water Sanitation Commission to bring in effective pollution control on the Ohio River.—M. D. J. B.

Coke Evaluation Project. (*Amer. Iron Steel Inst. Contributions to the Metallurgy of Steel No.* 43, 1953). This 159-page report presents the work of the American Iron Steel Institute Technical Committee on Coke Oven Practice, and its recommendations regarding a standard method of coke testing procedure with an empirical formula for the evaluation of metallurgical coke, and work on the relative importance of the chemical and physical coke tests.—R. A. R.

The Quality of Blast-Furnace Coke. F. J. Hewitt, H. L. Riley, and P. Savage. (*Year Book Coke Oven Man. Assoc.*, 1953, 185–213). The authors deal with the effect of under-carbonization on the quality of blast-furnace coke. Micro-strength tests and wet oxidation tests are described. More attention should be paid to coal crushing, bulk density, moisture control, and to the temperature and speed of carbonization. Blending is also advocated. Incomplete carbonization lowers the quality of blast-furnace coke.—R. P.

Coke Making for Blast Furnace from Hokkaido Coal. K. Hisada, M. Ota, and T. Koga. (*Tetsu to Hagane*, 1949, **35,** Sept., 287–290). [In Japanese]. The strength of coke made from high-volatile caking coal is increased by blending 20–30% of finely-ground semi-coke (0·3 mm. to 200 mesh) produced from non-caking coal. A similar, but less pronounced effect is found with coke breeze.—K. E. J.

Siderurgical Coke—Results and Conclusions Concerning Tests on the Coking of Soft Smithy Coals Mixed with Hard Steam Coal and Soft Coking Coal. F. Pintado Fe and J. R. Garcia-Conde. (*Inst. Nac. Carbon Bol. Inf.*, 1952, (6), Nov., 5–15). [In Spanish]. Little coking coal is available in Spain and the authors present tables of analyses of Spanish coals and of cokes made from them. Curves indicate the swelling properties as a function of the temperature.—F. R. H.

Research and Development on the Conversion of Coal to Gas, Liquid Fuels, and Bulk Organic Chemicals. H. H. Storch. (*Canad. Min. Met. Bull.*, 1953, **46,** Nov., 690–694). The relation between the structure and rank of a coal is discussed and a polynuclear structure assumed. Processes for manufacturing organic chemicals, synthesis gas, liquid fuels, and high calorific value gas from coal are described.—A. G.

Mechanical Gas-Producer Design: Adaptability to the Gasification of Coke Breeze. R. V. Farnham. (*Iron Coal Trades Rev.*, 1954, **168,** Jan. 29, 259, 258). The author outlines the reasons for the increased scope for large mechanical gas-producers in the steel industry, and the design of such producers is discussed. The possibilities of gasifying coke breeze are also considered.—G. F.

A Complete Gasification Process. (*Gas World*, 1953, **138,** Dec. 19, 1578–1581). An illustrated account is given of the G.I. process which is used on the Continent for the complete gasification of high volatile, weakly swelling coals. The coal is pre-distilled in a retort to remove most of the volatile matter and the coke residue is then subject to cyclic gasification with steam in a generator beneath. The process of pre-distillation may be applied to any type of gasification, and gas from G.I. producers is being used to fire coke-ovens.—B. C. W.

Savings Possible Through the Use of the Ufer Process in Benzol Plant Light Oil Washing. J. P. Purdy. (*Blast Furn. Steel Plant*, 1953, **41,** Dec., 1451–1452, 1463, 1466).

Reactivity of Cokes to Carbon Dioxide as Measured by Adiabatic Cooling. H. L. Hou and A. A. Orning. (*Fuel*, 1954, **33,** Jan., 42–50). The Coal Research Laboratory reactivity test has been modified to give measurements of the adiabatic cooling rates of coke reacting with CO_2. The results obtained with this new method are given and discussed. An approximate linear relation between reacting indices determined with CO_2 and those with oxygen indicates that the tests may be used interchangeably.—B. G. B.

Modern Plants for the Gasification of Lignite Briquettes. D. Haarbeck. (*Demag News*, 1953, (131), 20–23). A short description of a DEMAG gas producer for the gasification of lignite is given together with some operational data.

Air Pollution and Remedies. J. J. Seaver. (*Iron Steel Eng.*, 1953, **30,** Oct., 94–95). To reduce dust in open-hearth furnace stack gases the use of refractory deflectors at the entrance to slag pockets to make the gases turn 180° is advocated.—R. A. R.

Air Pollution Control in Steel Industry. G. A. Howell. (*Iron Steel Eng.*, 1953, **30,** Oct., 91–94). Some results of size and chemical analyses of dust in gases from oil-fired open-hearth furnaces and blast-furnaces are presented. As a result of trials with a pilot plant, a full-scale plant has been designed to clean 135,000 cu. ft. of ferromanganese blast-furnace gas per minute.—R. A. R.

The Rôle of Electrical Precipitation in the Steel Industry. H. L. Richardson. (*Iron Steel Eng.*, 1953, **30,** Oct., 95-100). The principles and the operation of the Cottrell electric precipitator for gas cleaning are outlined, and the following applications are discussed : (1) Removing tar from coke-oven gas ; (2) cleaning coke-oven heating gas ; (3) secondary cleaning of blast-furnace gas ; (4) cleaning open-hearth furnace gas ; and (5) cleaning gases from sintering machines.—R. A. R.

Dust and Fume Problems in the Steel Industry. R. F. O'Mara. (*Iron Steel Eng.*, 1953, **30,** Oct., 100–106). Dust problems in sintering plants, coke screening plant, blast-furnaces, open-hearth furnaces, Bessemer converters, and electric steel furnaces are discussed and some cleaning efficiencies achieved are cited.—R. A. R.

The Electric Air Cleaner. G. F. Landgraf and R. W. McGuire. (*Iron Steel Eng.*, 1953, **30,** Oct., 106–110). A modification (patented by G. W. Penney, Pittsburgh, Pa.) of the fundamental electrostatic process of gas cleaning is described. It embodies separate ionizing and collecting sections. Methods of determining filter efficiencies and the Dill Dust-Spot Tester are also described.—R. A. R.

Gasholders for the Iron and Steel Industry: Variations in Piston Seal in the Waterless Types. T. H. Riley. (*Iron Coal Trades Rev.*, 1953, **167,** Dec. 18, 1415–1417). The author describes the principal features of the M.A.N. waterless holder, the Klonne dry-sealed holder, and the Wiggins fabric-sealed holder, which are the three main types of gasholder used in the iron and steel industry.—G. F.

TEMPERATURE MEASUREMENT AND CONTROL

Measurement of Temperature by Thermocouple and Galvanometer—Determining Error Due to Overdamping. L. G. A. Sims. (*Engineering*, 1954, **177,** Feb. 5, 180–181). The author gives a brief description of temperature measurement by thermocouple and galvanometer and shows the experimental procedure for calibrating them. He shows how to assess errors due to overdamping in the galvanometer.

Experiences with Immersion Pyrometers. G. Eichert. (*Stahl u. Eisen*, 1954, **74,** Jan. 14, 95–98). The design is given of a light-weight immersion pyrometer which has proved very successful in steelworks operation. Its main feature is the use of alumina-molybdenum cermet thermocouple tips, which have average lives of 7–8 dips (sometimes up to 16 dips) into basic melts at 1600–1700° C. With unalloyed steel, the temperature readings with this instrument are very close to those obtained with a colour pyrometer on a stream from a spoon, but with high chromium, nickel or molybdenum steels, the immersion pyrometer registered a temperature lower by some 50° C.—J. P.

The Open Circuit Thermocouple. R. D. Potter. (*Metal Progress.* 1953, **64,** Nov,, 80–81). The use of the open circuit thermocouple (the individual wires are not fused together but are joined to the ends of a sample or dipped in a melt) for the measurement of temperature during the study of phase changes from −40° to +1000° C., is described.—B. G. B.

A Twin Photocell Circuit Suitable for the Control of Thermostats and Furnaces. G. W. Benson and G. C. Benson. (*Rev. Sci. Instruments*, 1953, **24,** Nov., 1070–1071). A simplified double photocell circuit is described. In two applications given, a furnace was controlled at 800° C. within ± 3° C., and a 40 litre water bath was controlled to ± 0·01° C. It is claimed that the performance could be greatly improved.

Iron-Constantan Thermocouple Tables. (*Indust. Heating*, 1953, **20,** Dec., 2382–2388). Details are given of reference tables prepared by the National Bureau of Standards for a series of commercial iron-constantan thermocouples covering

the range −310° to +1600° F. Calibration techniques are described.—R. W. B.

Measuring Fine Temperature Changes—Provision of a Constant Thermal Datum for Thermocouples. L. G. A. Sims. (*Engineering*, 1954, **177,** Jan. 1, 15–16). The author considers the calibration of thermocouples and the provision of a very stable cold junction (or thermal datum) without which high accuracy with the couple is impossible.—M. D. J. B.

Study on the Substitute Material for Pt/Pt-Rh Thermocouple (II). H. Hotta. (*Tetsu to Hagane*, 1949, **35,** Jan., 13–15). [In Japanese]. Fe–Mo thermocouples, specially protected, gave results nearly equivalent to those from Pt/Pt-Rh couples for temperatures up to 1400° C.—K. E. J.

Measurement of Surface Temperature of Rotating Rolls. (*Metall*, 1953, **7,** Nov., 877). A brief description is given of an instrument for the measurement of the surface temperature of heated, rotating rolls. The transmitting element is a bi-metallic strip heated by radiation.—J. G. W.

Measurement of Bath Temperature above the Bottom. Rabaud. (*Centre Doc. Sidér, Circ. Inform. Tech.*, 1952, (12), 1734–1736). A magnesite tuyere was fitted through the converter wall, emerging 6 in. above the bottom. Temperature measurements were made through a pyrex observation window. Towards the end of decarburization sudden fluctuations made temperature reading difficult. These corresponded to projections in the converter flames. The sealing and the life of the tuyere are discussed.—A. G.

Calculating the Wall Temperatures of Industrial Furnaces. G. Hofmann. (*Met. u. Giesserei Techn.*, 1953, **3,** Oct., 432–439). Formulæ are developed for calculating the temperature gradients in furnace walls constructed of different combinations of materials.—R. A. R.

Method of Measuring and Rapidly Recording Flame Temperatures. A. Moutet. (*Recherche Aéronaut.*, 1952, May–June, 21–32 ; July–Aug., 21–30). Optical methods used to measure flame temperatures are considered and critically reviewed. A detailed account of a new method for the measurement and recording of flame temperatures is given. The method is based on the fundamental work of Kurlbaum and Féry and uses photo-multiplier tubes to compare the emission from the flame with a standard source ; it has an extremely rapid response. (30 references).—B. G. B.

Status of Immersion Pyrometry in Melting Operations. K. Guthmann. (*Stahl u. Eisen*, 1953, **73,** Dec. 17, 1693–1705). The present position of, and operational experience with, immersion thermocouple and radiation pyrometers is reviewed on the basis of French, American, and British postwar publications and of trials in Germany. Design, manipulation, and indicating instruments are described, and attention is called to the use of cermet electrode sheaths.—J. P.

Progress Review No. 27: Temperature Measurement. E. J. Burton and D. J. Weeks. (*J. Inst. Fuel*, 1953, **26,** Nov. 260–273). This is a comprehensive survey of the literature covering all aspects of temperature measurement. (120 references).

Temperature Measurement by Electrical Means. (*Canad. Metals*, 1953, **16,** Oct., 16–18). A short account of methods of measuring temperature with thermocouples or resistance thermometers is given.—B. G. B.

Metal-Ceramic Wall Lengthens Thermocouple Life. P. B. McSherry. (*Iron Age*. 1953, **172,** Oct. 29, 100–101). A material containing 77% chromium metal and 23% aluminium oxide by weight has properties not available in either metals or ceramics alone. Amongst other applications is its use as a sheath for thermocouples in checkers. An $\frac{1}{4}$ in. wall thickness gives rapid response to temperature fluctuations and it has a long life.—A. M. F.

Heat Treatment Control of Large Forgings. S. Burda and J. Růžička. (*Hutnické Listy*, 1953, **8,** (9), 454–460). [In Czech]. Principles and methods of temperature measurement and their relation to the desired properties of large forgings are discussed. Methods of non-destructive testing, including crack detection by means of magnetic powder, fluorescent materials, dyes, X-rays, gamma-rays and ultrasonics, are discussed. Present methods of control depend too much on individual judgment, and more objective methods, based on up-to-date measuring techniques, should be used.

REFRACTORY MATERIALS

A Glossary for the Refractories Industry. (*Refract. J.*, 1953, **9,** Sept., 385–389). Over 130 terms used in the refractories industry are briefly defined.—J. R. P.

A Study of the Brown Plastic Fireclays Occurring in the Transvaal, South Africa. H. Heystek and B. M. R. Chase. (*Trans. Brit. Ceramic. Soc.*, 1953, **52,** Sept., 482–495). The mineralogical composition of six semi-refractory plastic clays from the Transvaal were determined and the results are reported.—R. A. R.

Technological Processes Suggested by Present Trends in Refractory Materials. F. de Carli. (*Met. Ital.*, 1953, **45,** Oct., 355–362). The author discusses modern trends in the manufacture of refractories with special reference to physical, mechanical, and chemical requirements. The properties and uses of silica, alumina, mullite, magnesite, dolomite, chromite, spinel, and zircon oxides are described. (23 references).

Standard Refractory Tubes. (*Ceramics*, 1953, **5,** Aug., 263–265). The article deals with recrystallized alumina, mullite, and aluminious porcelain, tables of revised standard sizes being given.—J. R. P.

Processing the White Variety of Polish Magnesite. F. Nadachowski. (*Prace Instytutow Ministerstwa Hutnictwa*, 1953, **5,** (5), 245–258). [In Polish]. The possibilities of utilizing white Polish magnesite for the production of refractory clinker is discussed. The influence of the SiO_2 content of the raw material and sintering additions (Fe_2O_3 and CaO) on the refractoriness-under-load was investigated. As expected, calcium ferrites accelerated the sintering process but considerably reduced the refractoriness-under-load. A content of about 2% Fe_2O_3 proved to be the most advantageous.—V. G.

Basic Refractory Brick. (*Canad. Metals*, 1953, **16,** Dec., 31–32). **Most Modern Basic Refractory Brick Plant.** (*Canad. Min. J.*, 1953, **74,** Dec., 65). A very short description of a new plant at Marelan, Quebec, for the production of basic refractory bricks, is given.—B. G. B.

Push-button Plant. (*Amer. Ceram. Soc. Bull.*, 1953, **32,** Nov.. 328–329 ; *Chemical Eng.*, 1953, **60,** Oct., 120–122). **Improved Silica Brick.** (*Metal Progress*, 1953, **64,** Oct., 161–166). The silica refractories plant of the Harbison-Walker Refractories Co., at Windham, Ohio, is described. The operations are highly mechanized and largely automatic.—D. L. C. P.

Silicious Schist for the Manufacture of Silica Bricks. R. Bárta, J. Vašíček, and O. Vepřek. (*Hutnické Listy*, 1954, **9,** (1), 11–17). [In Czech]. Tests were carried out on laboratory specimens of Dinas made from silicious schist found in Czechoslovakia. It is shown that the bricks maintain their strength up to about 1680, or even 1700° C., so that they are not appreciably inferior in that respect to superduty silica bricks. However, their softening range is narrow, and their use is only justified with good furnace roof temperature control.—P. F.

The Magnesite Deposits of Tux. F. Angel and P. Weiss. (*Radex Rundschau*, 1953, Aug.–Sept., (7–8), 335–352). The geology, structure, and constituents of the magnesite deposits near Tux, Tyrol, are described. There are two deposits, one very low in iron. Problems of their origin are discussed.

Present Trends in the Construction of Modern Dolomite Works. Richard. (*Centre Doc. Sidér, Circ. Inform. Tech.*, 1952, (12), 1722–1726). In modern works the raw material descends by gravity from the highest point thus minimizing handling. Control of dolomite mixtures is often empirical, desirable measures being : (*a*) Automatic control of dolomite grain size, and the proportions of dolomite and tar ; and (*b*) an increase in productivity. Methods employed at the Laïes Works, Trèves, are outlined.—A. G.

Steels Refractories Made with Sludge Arising in China Clay Production. R. Schröter. (*Met. u. Giesserei Techn.*, 1953, **3,** Nov., 487–488). The author describes successful attempts at Colditz in Eastern Germany to use sludge available as a waste product in the china-clay industry, in the manufacture of refractories, instead of the fireclay previously used.—R. A. R.

Hydration-Resistant Magnesite Refractories. P. Lanser and N. Skalla. (*Radex Rundschau*, 1953, July, (6), 40–43). Refractories, almost hydration resistant, can be produced by blocking active periclase points with CO_2, SO_2, or certain salt solutions. The hydration resistance remains unaffected up to 500–950° C. The various types of treatment and resulting hydration resistance are discussed in brief.—E. C.

The Specific Heat and Thermal Conductivity of Graphite. P. G. Klemens. (*Australian J. Physics*, 1953, **6,** Dec., 405–409).

Instruments for Testing Refractory Materials Used in Electric Furnace Construction. H. Kalpers. (*Elektrowärme-Techn.*, 1953, **4,** Dec., 146–147). Creep testing equipment for temperatures up to 1800° C. and over, compression testing, thermal cycling, and abrasion testing equipment for use on refractories are described.—P. F.

An Electromagnetic Viscometer for Molten Silicates at Temperatures up to 1800° C. J. O'M. Bockris and D. C. Lowe. (*J. Sci. Instruments*, 1953, **30,** Nov., 403–405). Using a molybdenum apparatus, the concentric cylinders method, and an electromagnetic method of torque measurement, temperatures up to 1820° C. can be applied and an accuracy of ±3% obtained at 1800° C. The construction, operation, and method of calibration of the apparatus are described.—L. D. H.

Some Physical-Chemical Aspects of the Refractory Brick Industry. G. van Gijn. (*Chem. Week.*, 1953, **49,** Dec. 5, 928–932). [In Dutch]. Basing his remarks on the SiO_2–Al_2O_3 binary equilibrium diagram, the author discusses the minerals used in the manufacture of silica, fireclay, and sillimanite materials, including the reaction and conversion products formed during firing.—F. R. H.

Examination of Refractory Specimens in Reflected Light. R. B. Snow. (*J. Amer. Ceram. Soc.*, 1953, **36,** Sept., 299–304). A mounting and polishing technique is described for preparing refractory specimens for examination under a good metallurgical microscope. The method is useful for investigating the failures (in service) of refractory materials in the metal industries. Silicates, oxides, and other mineral and metallic constituents can be picked out ; illustrated examples are given.

The Influence of a CO_2 Atmosphere on the Speed of Decomposition of Magensium Carbonate. E. Cremer, K. Allgeuer, and W. Aschenbrenner. (*Radex Rundschau*, 1953, (9–10), Nov., 494–502). The decomposition of pure synthetic magnesium carbonate was investigated *in vacuo* and under various constant CO_2 pressures at 750, 800, and 850° K. In *vacuo* a first order reaction occurred with a half change period of 73 min. and an activation energy of 37 kg. cal. Under constant CO_2 pressures, diffusion controlled the rate of decomposition. The diffusion progresses unidirectionally and its constant depends on pressure. Full details are given of methods and results.—E. C.

Wear of Magnesite Refractories in Steel Furnaces. F. Nadachowski. (*Hutnik*, 1954, **21,** (1), 6–12). [In Polish]. The mineralogical composition and properties of the main components of magnesite refractories are outlined. The mechanism of corrosion and the effects of iron oxides, calcium silicates, and other factors are discussed. It is proposed to improve the properties of refractories produced from low grade magnesite by additions of stabilized dolomite in order to improve the CaO/SiO_2 ratio.—V. G.

Recent Progress in the Composition of Hydraulic Refractory Cements. J. Arnould. (*Chim. et Ind.*, 1953, **70,** Dec., 1081–1085). The properties of refractory cements based on calcium aluminate are given and discussed. The composition of the cement is 70–72% Al_2O_3, 26–29% CaO, 0·5–1% SiO_2, and 0·5% Fe_2O_3. The fusion point of the pure cement is 1580° C. but is raised to 1745° C. when mixed with pure alumina. Graphs showing the variation of strength with time and thermal conductivity with temperature are given. Certain advantages over ordinary alumina cements are claimed for the new cement.—B. G. B.

Results of Electron Microscope Investigation of Hungarian Bentonites and a Halloysite Sample from Felnémet. K. Arkosi and J. Barna. (*Acta Techn.*, 1953, **7,** (1–2), 71–88). [In English].

Standard Refractories for Tapping Steel. (*Jernkontorets Ann.*, 1953, **137,** (11), 791–815). [In Swedish]. The Swedish committee on materials for lining furnaces and ladles has now published details of revisions to the standard refractories for ladle stoppers and nozzles, nozzle seatings, trumpet bricks, stopper sleeves, and mould bottom bricks.—G. G. K.

My Job in Relation to Productivity—The Selection of Steelworks Refractories. H. R. Tufnail. (*Swansea Met. Soc.*, Apr. 11, 1953, 11–19). The author, a refractories chemist, discusses the selection of refractories for, and construction of, an open-hearth steel furnace in relation to productivity. The choice of refractories in soaking pits is also considered.—L. E. W.

Development of Open-Hearth Roof Refractories in Great Britain. J. Mackenzie. (*Amer. Ceram. Soc. Bull.*, 1953, **32,** Nov., 377–384). An account is given of trends in open-hearth roofing practice in Great Britain. The grades of silica bricks used are described and the development and trial of silcrete bricks are dealt with. At present silcrete is most favoured as strips in selected spots, or for laying zebra fashion. Experience with basic bricks is summarized.—D. L. C. P.

Heat Resisting and Insulating Materials. (*Hutnik* (Prague), 1953, **3,** (12), 280–285). [In Czech]. The classification, physical properties, and standardization of acid, semi-acid, basic, carbonaceous, and neutral refractory materials, both natural and synthetic, are discussed.—P. F.

Thermal Conductivity of Refractory Insulating Concrete. W. C. Hansen and A. F. Livorich. (*J. Amer. Ceram. Soc.*, 1953, **36,** Nov., 356–362). The thermal conductivities and bulk densities of 17 insulating concretes (calcium aluminate cement " Lumnite ", with a variety of aggregates) were determined over the temperature range 500–2000° F. The experimental procedure is given and the results are shown as tables and graphs.—D. L. C. P.

Refractory Cement. J. E. Lafon. (*Mét. Constr. Mécan.*, 1953, **85,** Sept., 717–721, 731). The preparation, composition, properties and uses of a number of cements suitable for use at high temperatures are considered.—B. G. B.

New Uses for Ceramics. (*Machinist*, 1954, **98,** Jan. 2, 34–35). The properties and some applications of ' Sintox ' (sinter alumina), produced by Lodge Plugs Ltd., Rugby, are described. The material has a sp. gr. of 3·7, an ultimate strength of 10,800 lb./sq. in. and a volume resistivity at 14° C. of 10^{16} ohm. cm. It can be used as a shroud over a welding electrode to direct a stream of protective gas round the arc.

Refractories for Every Use. C. L. Norton, jun. (*Chem. Eng.*, 1953, **60,** June, 216–220). Details are given of the production and uses of the different types of refractory available including alumina-silica, magnesite, silicon carbide, metal-ceramic combinations, and special high temperature refractories (melting above 4000° F.)—A. G.

Insulation for Heat and Cold. R. Thomas. (*Chem. Eng.*, 1953, **60,** June, 221–225). A table of material characteristics of 19 insulating materials is given and the factors governing the choice of insulation are discussed.—A. G.

BLAST-FURNACE PRACTICE AND PRODUCTION OF PIG IRON

Iron and Steel by the Oxygen Impingement Process. P. E. Mehta. (*J. Sci. Indust. Res.*, 1953, **12,** Oct., 443–444). It is felt that the use of oxygen-enrichment in blast furnaces and converters should be investigated as a source of economy and greater output in the Indian iron and steel industry.—J. O. L.

An Investigation of the Blast-Furnace of Wanishi Iron Works. (I). K. Tawara and A. Suzuki. (*Tetsu to Hagane*, 1949, **35,** Nov., 369–373). [In Japanese]. Furnace trials are reported which threw some light on operating irregularities in a furnace using Hokkaido bog ores and high-ash cokes.

An Investigation of the Blast-Furnace at Wanishi Iron Works (II). K. Tawara and T. Uno. (*Tetsu to Hagane*, 1949, **35,** Dec., 413–425). [In Japanese]. A report is given of full-scale tests on a furnace operating on bog ores ; determinations were made of temperatures at the wall and through the stock-column, gas compositions, and flue dust.—K. E. J.

Method for Smelting Titanium-Containing Iron Sand in the Blast-Furnace. K. Taniguchi and T. Yagi. (*Tetsu to Hagane*, 1949, **35,** Jan., 2–8). [In Japanese]. Titanium-containing iron ore cannot be smelted normally, as a result of the increasing formation of solid matter in the hearth (ferrotitanium and compounds resulting from reduction of TiO_2). Tests on an experimental furnace and small blast-furnaces showed that successful smelting depends on (*a*) CaO/SiO_2 ratio of 0·8–0·9, (*b*) prevention of reduction of TiO_2 by low furnace temperatures, and (*c*) the use of more manganese to increase slag fluidity and assist desulphurization. (12 references).

New Type Tuyeres for High and Low Shaft Furnaces. H. Mathiske and W. Muschter. (*Met. u. Giesserei Techn.*, 1953, **3,** Nov., 474–475). Attempts have been made to find a substitute for copper tuyeres. It may be possible to use an " industrial porcelain " but tests have not yet been concluded. Experiments with light metals proved unsatisfactory, but the results of tests with aluminized steel plates are promising.—L. J. L.

Literature Research on Desulphurization of Pig Iron. N. Chvorinov. (*Hutnické Listy*, 1953, **8,** (11), 562–567). [In Czech]. British, German, and Russian papers on desulphurizing iron, from about 1935 onwards, are used as basis.

for an assessment of present methods. A research programme designed to solve current problems is proposed.—P. F.

Coke Consumption in the Remelting of Scrap, Pig Iron, and Granular Iron in the Blast-Furnace. P. Hüttemann and R. Mintrop. (*Tech. Mitt.*, 1952, Oct., (1), 39–43). The use of granulated iron in place of whole pigs results in a saving of coke of about 100 kg./ton of remelting material. Granular iron has other advantages, *e.g.*, protection of the upper parts of the furnace and coolers, and regular working of the furnace even with intermittent charging.—R. P.

Blast-Furnace Trials, with Particular Reference to the Problem of Nitrogen in Bessemer Iron and Steel. O. Vorwerk and W. Geller. (*Tech. Mitt.*, 1952, Oct., (1), 12–25). The sequence of reduction of elements in the blast-furnace is found to be in accordance with known results. A change in the temperature of the blast from 450 to 600° C. and simultaneous increase of the basicity of the slag does not affect the nitrogen content of the iron. The nitrogen content is increased more by scrap in the charge. Tests with the Bessemer converter showed that the nitrogen content of steel decreases with increase in basicity of the slag.—R. P.

B.I.S.R.A. Photo-Electric Dust Concentration Meter. (*Engineer*, 1954, **197,** Jan. 22, 128). A brief account is given of a photo-electric instrument developed by B.I.S.R.A. for providing a continuous quantitative record of dust concentration in blast-furnace gas.—M. D. J. B.

TREATMENT AND USE OF SLAGS

A Process for the Recovery of Manganese from Open Hearth Slags. H. W. Hosking and J. A. Gregory. (Australasian Inst. Metals : *Australasian Eng.*, 1953, Sept. 7, 44–55). A process has been developed by Broken Hill Proprietary Co. Ltd., Newcastle, Australia, for recovering manganese from open-hearth run-off and final slags in the form of a ferrosilicon-manganese containing up to 70% Mn. The process involves reduction of the slag in two stages. The first stage is carried out under acid conditions and produces a high-phosphorus iron, manganese being left in the slag. The second reduction uses the phosphorus-free slag to produce a manganese-rich alloy and a slag virtually free from metallic oxides and phosphorus. The full technology of the process is described, the cost being low enough to make it worthwhile in an emergency. (14 references).—P. M. C.

Constitution of Slags. P. E. Henry. (*Ann. Mines*, 1953, **142,** (8), 7–30). Slag constitution is discussed in the light of Frenkel's kinetic theory of liquids. Slags are considered to be essentially quasi-solid liquids. Fusion is characterized by a sudden increase in disorder (of position, composition or orientation), accompanied by a volume increase of nearly 10% due to an increase in vacant lattice sites in mobile mosaic domains. Slag viscosity is discussed and the success of the Frenkel theory in explaining the increase in viscosity with temperature is mentioned. The electrochemical properties of slags are described. In acid slags bivalent metal oxides are completely ionized. In basic slags, the ions which carry the current are far less mobile than metallic cations. Various methods for studying slag constitution are reviewed, the most promising being the construction of cells such as one with liquid iron electrodes and two different slags having a small common surface.—A. G.

PRODUCTION OF STEEL

Seventh Hatfield Memorial Lecture: Developments in the Iron and Steel Industry in Great Britain During the Last Twenty-Five Years. T. P. Colclough. (*J. Iron Steel Inst.*, 1954, **177,** July, 297–304). [This issue].

Some Important Developments During 1953 in Iron and Steel Technology. (*United Nations Economic and Social Council*, E/ECE/171, E/ECE/STEEL/78, Jan. 7, 1954). This report brings together and describes in simple terms the main developments which have taken place and the direction in which new developments may be expected. The information is based mainly on articles from the world technical press.

Expansion at the Steel Company of Wales. T. J. Ess. (*Iron Steel Eng.*, 1953, **30,** Nov., 105–120). A detailed account is given of the new installations at the Margam, Abbey, and Trostre Works of The Steel Company of Wales. The description covers all items including the discharge of ships, iron making, steel making, hot and cold rolling, tinplating, and services.—M. D. J. B.

Allegheny Ludlum. T. J. Ess. (*Iron Steel Eng.*, 1953, **30,** Dec., 87–102). The author traces the origins of the Allegheny Steel and Iron Co. and describes in detail the modernized Brackenridge and West Leechburg plants of this company. The steelmaking units, blooming mill, strip mill, cold finishing stands and the plate mill are described.—M. D. J. B.

The B.I.S.R.A. Sheffield Group. Sir Charles Goodeve. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 489–491). A brief review is presented of the conception, choice of site, selection of research programmes, and activities, of the new Sheffield Group Laboratories of B.I.S.R.A. The Group comprises metal working, steelmaking, and metallurgy laboratories.

The New Buildings for the B.I.S.R.A. Sheffield Laboratories. W. C. F. Hessenberg, C. N. Kington, and H. C. Husband. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 492–497). The laboratories comprise a three-storey main laboratory and office block of approximately 30,000 sq. ft. floor area, a metal working shop of approximately 10,000 sq. ft. floor area, and a melting shop of approximately 4000 sq. ft. The layout, distribution of services, air conditioning system, method of construction, and materials used are described and illustrated.

Co-operative Research in Steelmaking. A. H. Leckie. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 505–507). A brief history of co-operative steelmaking research is presented, leading to the formation of the Steelmaking Division of the B.I.S.R.A. The function of the Division, and its fields of activity, are reviewed.—P. M. C.

Design and Operation of Open-Hearth Furnaces. R. Mayorcas and A. H. Leckie. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 508–514). The authors review the B.I.S.R.A. work on open-hearth furnace design and operation. Model work on a one-fifth scale furnace at the Shelton Iron, Steel, and Coal Co. has yielded valuable information concerning heat transfer to the hearth, roof temperatures, fuel/air ratios, and furnace pressures. This work is being continued on a one-twelfth scale model furnace at the Sheffield Laboratories. Details are also given of field work, and the progress made with open-hearth instrumentation and automatic control. (22 references).—P. M. C.

Bessemer and Electric Steelmaking. D. J. O. Brandt and W. H. Glaisher. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 515, 516, 524). The research activities of B.I.S.R.A. in these fields are outlined. Although no direct work on the Bessemer process is carried out in the new Sheffield Laboratories, reference is made to B.I.S.R.A.'s part in the development of a related process—the pretreatment of open-hearth iron by oxygen desiliconizing. An outline is given of the work in progress on the 10-cwt. experimental arc furnace. Controlled studies of electrode wear and power consumption are being made in which the independent variables are rate of power input, roof height, size of charge, and type of scrap.

Research on Process Chemistry. C. E. A. Shanahan. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 517–520). The author reviews the work being carried out on the physical chemistry of steelmaking, in the B.I.S.R.A. Sheffield Laboratories. The problem of sulphur removal in open-hearth furnace operation has received much attention, and a detailed study of the soda ash process for desulphurizing pig iron is in progress. The influence of agitation on the reaction rate between metal and slag, also in connection with desulphurization is being studied.—P. M. C.

Ingots and Ingot Moulds. W. H. Glaisher. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 521–524). The author outlines the work being carried out in the B.I.S.R.A. Sheffield Laboratories under the auspices of the Ingots Committee of the Steelmaking Division. Problems in hand include continuous casting, the design of feeder heads for killed steel ingots, blowhole distribution in balanced steel ingots, solidification rates of forging ingots, ingot mould performance, and the determination of gas content in steel.—P. M. C.

The Wear of Ingot Moulds in Steelworks and the Effect of Chill Casting on their Durability. H. Poetter. (*Met. u. Giesserei Techn.*, 1953, **3,** Nov., 453–458). The most important causes of ingot mould failure are cracks in the mould wall and burning of the mould interior. To prevent the former, cast iron used should be soft but tough, whereas a close-grained cast-iron will best withstand the latter. Ferritic-pearlitic structure with finely divided graphite should therefore be aimed at.—L. J. L.

Developments in Ingot Mould Lacquers. G. Kowarsch. (*Stahl u. Eisen*, 1953, **73,** Dec. 3, 1654–1657 ; *Iron Steel Inst., Translation Series No.* 482, 1954). The development and

properties of a bitumen-benzine and a coumarone-benzol lacquer for ingot moulds are described. The lacquers can be used separately or as a mixture to suit the type of ingot being cast.—J. P.

Fundamentals of the Production Process in Transformer Sheet Manufacture. M. Jarolim. (*Hutnické Listy*, 1953, **8**, (11), 581–584). [In Czech]. The most important aspects of transformer steel production, particularly the choice of pure materials for the electric furnace charge, and the methods of alloying with silicon are discussed. Decarburizing in the furnace, power-loss of the sheet in relation to the sulphur content, and grain-refining are considered.—P. F.

The Production of Transformer Sheet. A. Loch. (*Foundry News* (Katowice), 1953, (2), 3–7: *Met. u. Giesserei Techn.*, 1953, **3**, Sept., 375–378). The author examines the effect of the chemical composition and the melting procedure upon the magnetic characteristics of transformer steel and goes on to discuss heat-treatment and etching. He considers the ideal composition to be C 0·05–0·08%, Mn 0·10–0·15%, Si 3·9–4·2% and P and S each 0·015%.—L. J. L.

Development and Status of the Manufacture of Dynamo and Transformer Sheet. H-H. Meyer and H. Schlüter. (*Stahl u. Eisen*, 1953, **73**, Dec. 17, 1706–1717). Literature on this subject during the past 15 years is reviewed and the results therein are compared with those obtained by the authors. Watt losses can be reduced to low values only if the material contains the minimum of carbon, manganese, sulphur, phosphorus, chromium, and copper. Oxygen is also detrimental, especially when present as alumina. Presumably the lower oxygen content of electric furnace steel is the reason for its superiority over open-hearth steel, though both types have the same magnetic properties after annealing in hydrogen. The effects of rolling and annealing conditions on the properties of transformer sheet are discussed and procedures to prevent sheets sticking together are mentioned. Improved properties result from cold rolling and annealing, and further improvement can be effected by cooling in a magnetic field.—J. P.

The Compagnie des Forges de Chatillon-Commentry Is Over 100 Years Old. (*Usine Nouvelle*, 1953, **9**, Nov. 5, 22–23). A brief survey of development to the present position of this company, now employing 11,500 workers, is given. The company is organized in four main groups: Central, Northern, Eastern and Wiredrawing, comprising iron and steel plant, rolling mills, and steel founding, with iron ore and coal concessions. Recent improvements include a new coking plant (400,000 tons/year) an ore preparation plant, and modernization of the steel plant at the Neuves-Maisons works, (Eastern group). The company is developing exclusive European rights on the cold rolling of silicon steel sheets for transformers.—A. G.

Dephosphorization of Basic-Bessemer Steel by a Double Carbonate of Sodium and Calcium. Cohu. (*Centre Doc. Sidér., Circ. Inform. Tech.*, 1952, (12), 1727–1734). To avoid the disadvantage of volatization accompanying the use of sodium carbonate for dephosphorization trials have been performed with the addition of 10 kg./ton of a mixed carbonate containing approximately equal amounts of sodium and calcium. No practical difficulties were met and the purity of the steel was improved, by reducing by 0·007% the mean phosphorus content and that of nitrogen by 0·0025%.—A. G.

Use of Oxygen in a Basic Bessemer Steelworks. Delong. (*Centre Doc. Sidér, Circ. Inform. Tech.*, 1952, (12), 1736–1739). At the Rombas works, oxygen is supplied from a generating plant to the steelworks through a 4-in. pipe, and trials have been made with an oxygen-enriched blast. Oxygen was introduced after the silicon blow in amounts of 240 and 360 cu. m. With a relatively large converter and a low-silicon iron, blowing time was cut from 15 min. to 8 min. 48 sec. and nitrogen content fell from 0·014% to p·005%.—A. G.

The Problem of Deoxidizing Bessemer Steel. W. Krumnacker. (*Met. u. Giesserei Techn.*, 1953, **3**, Dec., 540–543). Having discussed some of the problems concerned the author concludes that: (1) Aluminium in some form or other must be used to deoxidize Bessemer steels; (2) ferromanganese preheated to 500° C. added to the ladle is a useful addition; and (3) ferromanganese and ferrosilicon additions should be in small pieces.—R. A. R.

Investigations on the Temperature Losses from Basic Iron. W. Jäniche and H. Beck. (*Tech. Mitt.*, 1952, Oct., (1), 26–38). Thermocouples are more accurate than optical pyrometers although the latter are cheaper. The temperature of the pig iron was measured on its way to the converter. In the runner and ladle the temperature depends on the working conditions of the blast-furnace and this influences the decrease in temperature in transit. These losses are also determined by circulation in the ladle, its lining and the quantity. Temperature losses in the mixer depend on the weight of pig iron and the firing. The yield, blowing time, and nitrogen content of the steel are affected adversely by lowering the pig-iron temperature. (21 references).—R. P.

The Use of Cooling Agents in Bessemer Steelworks, Particularly Granular Iron. A. Schildkötter and H. Beck. (*Tech. Mitt.*, 1952, Oct., (1), 44–56). Contrary to prevailing opinion, it was found that the cooling actions of ore, granulated iron and scrap are similar for equal amounts and are not influenced by the time at which the addition is made. Increased additions of granulated material lower the phosphorus and nitrogen content and slightly increase the sulphur, due mainly to their dependence on the temperature; the manganese content is not affected. Less iron entered the slag if granular material is used than is the case with ore or scrap. (22 references).

Comparison of Auxiliary Furnace Equipment in Basic Open Hearth Plants. (*Amer. Iron Steel Inst. Contributions to the Metallurgy of Steel No.* 40, 1952). This 252-page report presents in tabular form a comparison of the open-hearth furnaces and auxiliary equipment of 18 American companies producing steel. The survey was intended to assist in the selection of additional equipment which would increase the production of existing furnaces with minimum capital outlay.

Inland Steel Increases Normal Open-Hearth Capacity 750,000 tons. (*Blast Furn. Steel Plant*, 1953, **41**, Jan., 75–80, 86; Feb., 203–208). A description is given of a new open-hearth shop containing four 250-ton furnaces installed at the Indiana Harbour Works. Details of the shop layout, auxiliary equipment, and the furnace design are given. The new furnaces are equipped with several indicating and control instruments the purpose of which is discussed.—B. G. B.

The Behavior of Zirconium and Titanium in Steels. (*Amer. Iron Steel Inst. Contributions to the Metallurgy of Steel No.* 41, Dec., 1952). This 37-page report summarizes the results of research on the use of zirconium and titanium as substitutes for manganese in steelmaking. The influence of increasing additions of these elements on the hot workability of low manganese steels was studied. Their effect is additive to that of manganese. The minimum Mn/S ratio, without additions, to prevent hot shortness is about 7·5, whereas with additions, minimum ratios are (Mn + Zr)/S = 5·0 and (Mn + Ti)/S = 5·5. These are approximate data for the steel tested which contained 0·03–0·04% S. As an emergency measure the substitution of titanium for manganese in killed steels is quite feasible.—R. A. R.

Developments in the Manufacture of Steel for Railway Materials in the Post-War Period. D. Craig. (*Rail Steel Topics*, 1953–54, **2**, Winter issue, 4–11). Acid and basic open-hearth steelmaking are described with special attention to the increase in instrumentation now applied.—A. D. H.

On the Consistency of the Entire Procedure in the Open-Hearth Process as Viewed from the Physico-Chemical Standpoint. T. Onaka. (*Tetsu to Hagane*, 1949, **35**, Apr., 94–98; May, 125–127; June, 159–162; July, 197–201; Sept., 291–293; Oct., 329–334). [In Japanese]. This article is a critical literature review. Silicon, manganese, and carbon are used to prevent oxidation of the bath, carbon being of greater importance as temperatures rise: it must be utilized by the mechanism of reaction with oxygen, with a vigorous discharge of CO. A detailed analysis is given of the reaction between carbon and oxygen in the ore introduced. Decarburization and rise of temperature in the bath are critically discussed. Addition of ore should be stopped when the temperature reaches the required level, to avoid bath oxidation; the decarburization velocity should be a maximum at this point. This survey shows that the operations in the acid open-hearth furnace are in accordance with chemical and physical theory. The final stages of melting, and the attainment of correct silicon, manganese, and carbon contents, and the fundamental equilibria occurring in the metal and acid slag, involving iron, manganese, silicon, carbon, and oxygen, are discussed.—K. E. J.

On the Reaction of Chromium under Basic Slag. T. Saito. (*Tetsu to Hagane*, 1949, **35**, Apr., 98–103; June, 168–173). [In Japanese]. In basic slag (with $CaO/SiO_2 > 2$), the reaction can be expressed as $2[Cr] + 3(FeO) \rightleftharpoons (Cr_2O_3) + 3[Fe]$. An

expression for the temperature coefficient of the equilibrium constant is proposed. Thermodynamic and practical considerations show that, as the FeO content in the slag increases, the Cr_2O_3 content falls. The removal of chromium from the bath is better at lower temperatures. Comparisons between acid and basic furnace practice are made.—K. E. J.

First Summarized Report of the Basic Open-Hearth Research Committee of the Iron and Steel Institute of Japan. H. Kikkawa. (*Tetsu to Hagane*, 1949, **35**, Jan., 9–13). [In Japanese]. As a result of work to assist post-war steelmaking with high proportions of scrap, the following conclusions were reached: (*a*) By the use of carburizing materials, the amount of iron in the charge can be reduced to 25%, (*b*) no particular advantage can be attributed to any one design of oil burner, and (*c*) raw dolomite beds can give satisfactory results. The use of oxygen was discussed.—K. E. J.

Use of Oxygen in the Open-Hearth Steel Making. S. Ichida. (*Tetsu to Hagane*, 1949, **35**, June, 153–159). [In Japanese]. Experimental procedures at the Amagasaki Steel Co., designed to shorten melt-down, included the introduction of oxygen at the burner, and its use through a jet directly on to preheated scrap; it was also used for decarburization of the molten bath. Its use resulted in increased production and reduced fuel consumption, while steel quality and yield were equal to those of normal practice.—K. E. J.

Trials with More Basic Pig and Very Rusty Turnings in the Charge. M. Borak. (*Met. u. Giesserei Techn.*, 1953, **3**, Oct., 424–425). At the Henningsdorf steelworks successful trials were conducted which proved that the unusually high amounts of manganese, silicon, phosphorus, and sulphur introduced into the open-hearth furnace by the high proportion of basic pig could be oxidised by charging very rusty turnings of which there was a plentiful supply. Satisfactory steel was produced.

The Suitability of German Bauxite as Fluxing Agent in the Desulphurization in the Basic Open-Hearth Furnace. K.-F. Lüdemann. (*Met. u. Giesserei Techn.*, 1953, **3**, Nov., 469–471). The author describes trials which proved that bauxite could be used instead of fluorspar as a flux for desulphurizing basic open-hearth heats.—R. A. R.

Measurement, Control and Mechanization in Metallurgy. M. Křejčík, and A. Winkler. (*Hutnické Listy*, 1953, **8**, (11), 578–581). [In Czech]. The prerequisites for fuller instrumentation of metallurgical processes in foundries and steelworks are discussed. Remote control and choice of suitable equipment are considered. The parameters measured on fully equipped Russian blast-furnaces and open-hearth furnaces, and overall fuel control in steelworks are listed.—P. F.

Dimensions of Ports for Maerz-Type Furnaces. W. Schmitt. (*Stahl u. Eisen*, 1953, **73**, Dec. 3, 1640–1643). Operational data from 13 open-hearth furnaces, obtained by a questionnaire, have been used to discuss flow patterns therein and to explain some works' experiences. Rules for efficient port design cannot be drawn up, although unfavourable influences of limited draught and bad distribution of waste gas in the air and gas checkers have been noted.—J. P.

Large Electric Furnace of the Future May be Six-Electrode Unit. F. W. Brooke. (*Iron Steel Eng.*, 1953, **30**, Nov., 123–129). The author discusses the possibility of constructing large electric furnaces with six electrodes and a capacity of 240 tons. These furnaces could be introduced into an existing open-hearth shop and would be worthwhile even on plain carbon steels. The conversion would cost approximately one million dollars per furnace but the installation would produce about twice the tonnage of ingots per hour.—M. D. J. B.

On the Rimmed Ingot Making by Héroult Furnace Using the Reducing Slag. S. Fukabori, S. Takao, and T. Komuro. (*Tetsu to Hagane*, 1949, **35**, Oct., 334–338). [In Japanese]. With reducing instead of oxidizing slag, rimmed ingots were made. The advantages are a more stable process, higher scrap usage, better ferromanganese yield, and good steel quality. This appears to be a promising method of making sound semi-killed ingots without using ferrosilicon or aluminium.—K. E. J.

On the Melting of High Mn–Cr Steel by the Basic Arc Furnace. Y. Shimokawa. (*Tetsu to Hagane*, 1949, **35**, July, 202–206). [In Japanese]. Magnesia refractories are not attacked by the molten steel, and manganese variation in the range 5–15% does not affect refractory erosion. Trials showed that the steel could be made conveniently in the basic arc furnace. Steel high in nitrogen could be made by suitable additions of nitrides of manganese, magnesium, calcium, and silicon.—K. E. J.

The Relation between the Deoxidation Products and the Smelting in the Basic Arc Furnace. Y. Shimokawa. (*Tetsu to Hagane*, 1949, **35**, June, 162–167). [In Japanese]. Statistical analyses showed the following results: Inclusions increase with increase of the oxidation period and smelting period, but decrease with manganese content; SiO_2 inclusions decrease with increase of CaO and basicity, whilst Al_2O_3 shows the reverse; the reduction of deoxidation products is best achieved by careful control of FeO in the oxidation period and slag control in the reduction period.—K. E. J.

Refining with High Purity Oxygen. O. Brandau and G. Tschorn. (*Met. u. Giesserei Techn.*, 1953, **3**, Oct., 401–411). The author discusses the introduction of the processes in the electric arc furnaces of Eastern Germany. A saving of more than 50% of ferrochromium, ferromolybdenum and nickel has been obtained, and a saving in electric power of up to 22% is claimed. Oxygen refining will never oust refining with ore and mill-scale in the production of ordinary steels, but it has become indispensable in the production of high-alloy chromium and chromium-nickel steels—L. J. L.

Induction Furnaces with Combined Series-Parallel Compensation. W. Scheibe. (*Elektowärme-Techn.*, 1953, **4**, Dec., 133–135). A circuit for phase-angle compensation facilitating the attainment of greater flexibility in applicability and design of high-frequency furnaces, and an increase in their efficiency is described.—P. F.

On the Basic Open-Hearth Slag. (The Simple Deciding Method of Slag Composition and Few Effects on the Molten Bath). Y. Kanamori. (*Tetsu to Hagane*, 1949, **35**, Sept., 294–296). [In Japanese]. A simple and rapid method of estimating the FeO content and the CaO/SiO_2 ratio of the slag is based on the colour of a powdered sample. The effects of slag composition on the carbon and phosphorus contents in the bath are discussed.—K. E. J.

Contribution to the Kinetics of Metallurgical Reactions. E. Plöckinger and H. Straube. (*Radex Rundschau*, 1953, July, (6), 3–7). Relationships between the equilibrium concentration and the total quantities of materials involved in homogeneous and heterogeneous reactions are discussed. Final equilibrium conditions are found to differ widely if the reaction between two phases is divided into separate successive operations. An optimum is reached if the slag additions are equal in the separate operations. Examples are quoted to show the possible effects on reactions between steel bath and slag. A general formula for all reactions in heterogeneous systems is derived.—E. C.

Some Elementary Thermodynamics of Refining. V. Kondic. (*Bull. Inst. Metals*, 1953, **2**, Dec., 35–37). A short account of the basic principles of the application of thermodynamics to the refining of metals is presented.—B. G. B.

Method for the Determination and Elimination of Non-Metallic Inclusions in Molten Steel. K. Koshiya. (*Tetsu to Hagane*, 1949, **35**, Nov., 401–405; Dec., 434–440). [In Japanese]. Methods of analysis for inclusions were examined, the HNO_3 method appearing most suitable. A procedure for sampling true inclusions (as opposed to those formed during solidification) is described. The effect of forging on the inclusion value is determined, and results of investigations in acid and basic open-hearth and electric arc furnace practice are given.—K. E. J.

The Study of Non-Metallic Inclusions in Steel. M. Sicha. (*Hutnické Listy*, 1953, **8**, (10), 506–512; (11), 567–577). [In Czech]. A detailed study is made of inclusions, their effects and origin. First the nature of inclusions, their relation to the mechanical properties of the steel, and their extraction and analysis by chemical and X-ray methods are discussed. The equipment required for analysis is described, and the results are considered with reference to the diagrams showing the refractive indices, colours, hardness, and phases of the MnO–SiO_2–Al_2O_3 and other systems. Inclusions are classified into three groups: (1) Products of the deoxidation in the steel furnace; (2) products of reactions with the refractory lining; and (3) refractory grains removed from the lining by the erosive action of the liquid steel. The influence of aluminium additions on the quality of open-hearth and converter steels, and of additions of liquid silicomanganese on the deoxidation is discussed.—P. F.

PRODUCTION OF FERRO-ALLOYS

Ferroalloys. L. Schmidt and F. Harms. (*Radex Rundschau*, 1952, (7), Dec., 283–292 ; 1953, (1), Jan., 9–24). Completion of a series of articles, *see J. Iron Steel Inst.*, 1953, **175,** Nov., 334. The December issue deals with vanadium, the January issue covers molybdenum, tungsten, and titanium. For each metal, natural occurrence, ores, world production, and reserves are surveyed in brief. Methods of production and alloying are described and chemical and production data are quoted. Properties and specialized uses of the ferro-alloys are discussed. Attention is drawn to the world shortage in supply of alloying elements.—E. C.

Electrochemical and Electrometallurgical Industries of Canada. Part II—Quebec, The Maritime Provinces, and Newfoundland. A. C. Holm. (*J. Electrochem. Soc.*, 1954, **101,** Jan., 7c–16c). Among the items noted is the discovery in Quebec of a tremendous ore body of ilmenite containing some 88% of combined titanium and iron oxides and the development of an electric smelting process to treat this ore. This led to the formation of the Titanium Iron and Titanium Corp. in 1948.—R. A. R.

Electrolytic Production of Manganese. T. Banerjee. (*J. Sci. Indust. Res.*, 1953, **12,** Oct., 457–461). Details and a flow sheet are given for the production of electrolytic manganese from the rich Indian ores.—J. O. L.

Ferromanganese Production in Electric Arc, High, and Low Shaft Furnaces. G. Brückner. (*Met. u. Giesserei Techn.*, 1953, **3,** Dec., 508–514). Manganese resources available for the production of ferromanganese in Eastern Germany are critically examined, and manganese ore reduction is discussed. The use of dolomite as a basic addition lowers the manganese content of the slag and increases the manganese output. Manganese production in high- and low-shaft furnaces is more economical than in the electric arc furnace.—L. J. L.

FOUNDRY PRACTICE

Metal Casting Methods. J. B. McIntyre. (*Metallurgia*, 1953, **47,** Apr., 179–182 ; May 231–236 ; June, 292–294, **48,** July, 21–26 ; Aug., 63–66 ; Sept., 123–129 ; Oct., 165–168 ; Nov., 241–246 ; Dec., 273–276). In the first part a general review of casting methods for ferrous and non-ferrous metals is made. The second part is concerned with centrifugal casting, and its application to horizontal and vertical axis machines is discussed. Reference is made to the production of pipes, cylinder liners, and gear blanks. In the third part the use of continuous casting methods is considered. The casting of pig iron is dealt with briefly in the fourth part and some of the problems involved in the production of sound ingots and their solution are considered. The fifth part is concerned with non-ferrous ingots. In the sixth part the techniques of slush casting, press casting, pressure die casting, investment casting, and gravity die casting are explained. Sand casting methods are discussed in the seventh part and the properties of moulding sands and a description of the sand-cement moulding technique is given. Patterns and their production are considered. The eighth part is concerned with the gating and feeding of sand castings and the use of chills and are considered. Jobbing and mechanical moulding practice are briefly reviewed. The last part is concerned with cleaning and fettling practice. The operations necessary after the casting has been removed from the mould to prepare it for shipment are described. These include removal of surplus metal in the form of runners and risers and the removal of sand.—B. G. B.

The Mixing Ladle in an Iron Foundry. (*Fonderie*, 1952, July, 3518–3520). The use of a mixing ladle in an iron foundry is briefly described. It provides a continuous reservoir of molten metal and prevents the rapid cooling which occurs when metal is held in a small cupola.—B. C. W.

Making Valves on a Flow Production Basis. P. Trippe. (*Machinist*, 1954, **98,** Jan. 23, 145–147). Obtaining flow-production in the manufacture of valves is normally difficult because of the large variety of valves produced. At Audley Engineering Co. Ltd., where the 'Audco' valve is made, a high degree of flow-production has been made possible. A recent introduction is a special mechanical charging unit placed between two cupolas ; the bucket with its 6-cwt. charge, on reaching the charging level, can be swivelled to either cupola. The bucket is of the drop bottom type, and the bottom is automatically released and reclosed.—R. A. R.

On the Melting of Cast Iron by Electric Arc Furnace. T. Sato and K. Horikawa. (*Tetsu to Hagane*, 1953, **35,** Nov., 373–378). [In Japanese]. The effects of variations in furnace atmosphere on silicon in the metal, FeO in the slag, and other variables, were studied.—K. E. J.

Coke Quality—Carbon Pick Up. C. R. Austin. (*Foundry*, 1953, **81,** Oct., 116–121, 234). The fundamentals of carburization are discussed and results are presented of tests on a series of cokes to determine their relative carburizing powers with respect to solid and liquid iron. In the first series mild steel was heated at 1800° F. (980° C.) in contact with the crushed coke and the carbon pick-up was determined by analysis and by metallographic examination. In the second series molten Armco iron was covered with the coke and held at 3000° F. (1650° C.) for different times ; the carbon content was determined by analysis. The results for the various cokes are discussed and it is claimed that they are directly applicable to the results obtained in cupola practice.—B. C. W.

Desulphurizing Conditions in the Hot Blast Cupola. M. Guédras. (*Mét. Constr. Mécan.*, 1953, **85,** Nov., 863–865, 867). The desulphurizing and dephosphorizing reactions and the methods used in cupolas are considered with particular reference to magnesium slag practice.—B. G. B.

The Interdependence of Technical Data for Cupolas and Its Effect on Operations. G. Speer. (*Met. u. Giesserei Techn.*, 1953, **3,** Dec., 538–539). After examining about 300 cupolas, the author finds that the design of many of them is unsatisfactory. He explains what should be the relationship between certain dimensions and other factors, and shows the effect of different relationships on the melting practice and quality of the product.—R. A. R.

The Principal Characteristics of Cupolas. A. M. Plešinger. (*Slévárenství*, 1953, **1,** (7), 181–184). [In Czech]. In order to aquaint cupola operators with likely causes of irregular performance of cupolas a description of the construction and operating conditions of a typical cupola is given.—P. F.

The Cupola and the Superheating of Iron. J. Pascal. (*Mét. Constr. Mécan.*, 1953, **85,** July, 547–551 ; Aug., 607–609 ; Sept., 695–700 ; Oct., 779–784). Stages in the development in the design of the cupola are described. The efficiency of the heating process is discussed and the increase in the efficiency of heating obtained with hot blast is illustrated by graphs. An illustrated description of the method of preheating the air in 18 different designs of cupola is given. Investigations into the use of oxygen-enriched blast are discussed.—B. G. B.

The Autoslagging Forehearth and Continuous Tapping of the Cupola. (*Fonderie*, 1953, Aug., 3564–3569). Various designs of autoslagging forehearth are described and illustrated. By using a forehearth the cupola may be tapped continuously with the consequent advantage of smoother and more efficient running.—B. C. W.

Some Considerations of the Use of Scrap in the Cupola. C. Dennery. (*Fonderie*, 1953, Aug., 3539–3555). In order to decide whether iron can be satisfactorily produced from a cupola using a scrap charge and additions of silicon and manganese, the basic principles of cupola operation are reviewed. The aspects considered are : (*a*) The thermal balance in the cupola ; (*b*) factors affecting the temperature of the iron ; (*c*) the physical chemistry of the cupola reaction ; (*d*) factors affecting the metallurgical structure and the mechanical properties of the iron ; and (*e*) foundry problems likely to be encountered. The author concludes that iron can be made from scrap with less coke than is generally believed, but that proper grading of the coke and conditioning of the blast are essential for the best results.—B. C. W.

Atmospheric Pollution. L. C. McCabe. (*Indust. Eng. Chem.*, 1953, **45,** Nov., 109A–112A). A survey is given of methods of controlling dust emission from cupolas. Efficiencies approaching 100% are shown by the combinations of blast combustion and glass fibre filters, and blast combustion and electrostatic precipitator of a new type.—K. E. J.

Rapid Calculation of Charges for Grey Cast Iron. G. Ziegler . (*Met. u. Giesserei Techn.*, 1953, **3,** Sept., 381). The author briefly describes a new rapid charge calculator developed by R. Müller.—L. J. L.

A Note on the Mechanism of Second Stage Malleabilization. F. Brown. (*Foundry*, 1953, **81,** Oct., 108–109, 203–207). The mechanism of malleabilization is discussed by reference to the iron–silicon–graphite ternary system, and the isothermal transformation diagrams for the reactions austenite → ferrite + graphite, austenite → cementite + ferrite, and cementite →

ferrite + graphite are presented. Results show that in three commercial irons, treated under controlled conditions, the direct transformation from austenite to ferrite + graphite was the only one that occurred. The effects of hydrogen and the manganese/sulphur ratio on malleabilization are explained by reference to their influence on the transformation diagrams. In commercial practice the direct transformation can occur and the possibility of using this transformation must be considered in determining the most economical conditions for second-stage malleabilization.—B. C. W.

The Fundamentals of Casting Technique in the Production of Steel Castings. J. Czikel. (*Met. u. Giesserei Techn.*, 1953, **3**, Dec., 529–533). Given certain figures, such as quality of casting, weight, and wall thickness, it is possible to calculate casting temperature and casting velocities. Parameters are derived and a suitable nomogram is given.—L. J. L.

Powder Flame Cleaning. E. Zorn and K. Schöbel. (*Schweissen u. Schneiden*, 1953, **5**, Dec., s54–s56). The method and equipment used for cleaning the surface of steel castings by means of the oxy-acetylene flame into which iron powder is injected is described.—U. E.

Mold Design for Casting Steel in Sand. R. W. Tindula. (*Foundry*, 1953, **81**, Oct., 242–252). This is a summary of recent reports dealing with changes in design of moulds for steel castings. The aspects covered include work on gating and feeding, pressure feeding, Williams and atmospheric risers, necked-down and knock-off risers, and the use of exothermic and insulating feeders. Recent research on solidification is also considered. (52 references).—B. C. W.

Determination of Feeding Systems. R. A. Cech. (*Foundry*, 1953, **81**, Oct., 128–131). A simple procedure is outlined for determining the size and positioning of feeders in steel castings. Graphs are given for various width/thickness ratios of castings against feeder diameter, length of sound riser zone, and length of sound end zone. Some examples of the method are worked out.—B. C. W.

Gating and Risering of Castings. A. Kukla. (Inst. British Foundrymen : *Engineer Foundryman*, 1953, **18**, Oct., 95–103). After reviewing the principles of solidification of alloys, the author gives a comprehensive account of theoretical and practical factors involved in the provision of adequate gates and risers. Steel, grey iron, and aluminium alloys are considered in detail.—A. D. H.

Determination of the Dimensions of Directly Fed Runners. J. Přibyl and S. Šimoník. (*Slévárenství*, 1953, **1**, (7), 176–180). [In Czech]. The problem of the right dimensions of runners in relation to the size and shape of the casting, the casting temperature and the dimensions of the shrinkage cavity is discussed. Nomograms are developed for determining the size of the runners for various metals from a knowledge of the shrinkage per unit volume of metal, and the casting temperature.—P. F.

Shell Moulding—What Does it Cost? W. W. Coleman. (*Foundry*, 1953, **81**, Oct., 156, 158, 190–192). The installation and operation of the shell moulding process is discussed in terms of cost. An analysis is made of costs in producing a grey iron crankshaft.—B. C. W.

Shell Moulding. K. H. Coombs. (Inst. British Foundrymen : *Engineer Foundrymen*, 1953, **18**, Oct., 89–91 ; Nov., 79–85). The operations of shell moulding are fully described. The merits of the process are considered, and future trends are predicted.—A. D. H.

New Shell-Moulding Foundry in Production. (*Canad. Metals*, 1953, **16**, Nov., 24–26). The techniques employed in a new Canadian foundry which uses the shell-moulding process for grey iron casting are described. The foundry can produce 4 tons of good castings per 8-hr. shift and can run continuously on three shifts.—B. G. B.

Shell Moulding Steel Castings. (*Machinist*, 1954, **98**, Jan. 30, 188–190). The article describes the methods employed by Sheepbridge Steel Castings Ltd. for manufacturing steel castings by the shell moulding process on a production basis. It was found that the incidence of hot tearing was much reduced, and the surface quality was greatly improved.

The Investril System of "Lost-Wax" Precision Casting. (*Machinery*, 1953, **83**, Dec. 18, 1207–1209). The Investril system recently introduced by W. J. Hooker Ltd., London, shows how medium and small quantities of castings may be produced economically using the lost-wax precision casting process. Features of the Investril system include extensive use of rubber moulds and the dispensing of the primary investment coating. Centrifugal casting in conjuction with the above system is described.—M. A. K.

Some Tools for Quality Control in the Mechanised Jobbing Foundry. T. W. Curry. (*Foundry*, 1953, **81**, Oct., 110–113, 214–222). A detailed description is given of the procedures being used at the Lynchburg Foundry Co., Lynchburg, Va. for quality control. The output of scrap castings is analysed daily and the results of the analysis together with a study of customers' complaints indicates where improvements are necessary. An analysis is made of losses which cause the greatest expense. In the foundry a careful control is kept on all incoming materials and on the quality of the moulding sand. Chill tests are made on the metal and subsequently correlated with mechanical properties. The author concludes with a summary of the experimental projects under investigation in a pilot foundry which are intended to improve the quality of the castings.—B. C. W.

Porosity: Solidification Interval and the Phosphorus Eutectic. J. Léonard. (*Fonderie*, 1953, July, 3513–3517). In cast iron, extending the solidification range leads to greater porosity by giving a longer temperature range over which gas evolution can occur. High phosphorus contents increase the solidification range and also give greater porosity as a result of the contraction of the phosphorus eutectic.—B. C. W.

Use of Grinding Wheels—Safety Aspects. M. Hubert. (*Fonderie*, 1953, July, 3501–3512). The principles governing the safe and efficient use of grinding wheels in the foundry are discussed in detail. The aspects considered include the storage and handling of wheels, grinding machines, wheel mountings, the misuse of the wheels, correct grinding methods, and dressing of grinding wheels.—B. C. W.

Shot Peening in Ferrous Metallurgy. G. Giudicelli. (*Mét. Constr. Mécan.*, 1953, **85**, Sept., 723–729 ; Nov., 881–883). A description of different ways in which shot peening is used in the steel industry is given. They include methods for the batch treatment of small bars and other shapes, a continuous method for the treatment of tubing, and a machine for the treatment of rolling-mill rolls.—B. G. B.

HEATING FURNACES AND SOAKING PITS

Economical Refractory Bottom Developed for Reheating Furnaces. (*Iron Steel Eng.*, 1953, **30**, Nov., 135). A brief description is given of the Hyche method of building, maintaining, patching, and replacing continuous reheating furnace bottoms. The method consists of bonding pig iron, mill scale, chrome ore dust and magnesite. Amalgamation results in a hard abrasion-resistant monolithic bottom.—M. D. J. B.

Low Frequency Induction Coils Shorten Billet Heating Time. (*Iron Steel Eng.*, 1953, **30**, Nov., 130–132). A new method is described for heating billets, which, it is claimed, is five to ten times faster than conventional heating. Low frequency induction heating is used on the experimental furnace which is capable of dealing with billets of up to 1500 lb. in sizes up to 13 × 13 × 30 in.—M. D. J. B.

A Modern Automatic Fuel Shut-Off System for Soaking Pits. A. L. Lancaster. (*Iron Steel Eng.*, 1953, **30**, Dec., 69–76). The author describes modern soaking-pit construction of the two-way top-fired, one-way top-fired, and bottom-fired types. Detailed information is given of an automatic temperature control system which throttles down the valve in the fuel line when the correct soaking temperature is reached.

HEAT-TREATMENT AND HEAT-TREATMENT FURNACES

The Use of High Alloy Castings in Heat-Treating Equipment. (*Canad. Metals*, 1953, **16**, Nov., 28–32). Types of alloy steels suitable for continuous service in heat-treating equipment are considered. Iron–chromium–nickel (Cr 30%, Ni <7%) castings are suitable for strong oxidizing or reducing atmospheres with a high sulphur content and where only moderate strength is required. Castings with Cr 18–32% and Ni 8–22% have a greater strength under similar conditions. Where hot strength and reliability under varying temperature conditions are required, castings with Cr 10–20% and Ni 30–70% are suitable in most circumstances where the sulphur content of the gas is low.—B. G. B.

Heat Treatment of Steel Castings. J. H. Hall. (*Foundry*, 1953, **81**, Oct., 122–125, 264–265 ; Nov., 124–127, 242–248 ; Dec., 126–129, 194). The fundamentals of heat-treatment as

applied to steel castings are discussed with reference to both metallography and mechanical properties. The aspects covered include the iron–carbon diagram, isothermal transformation diagrams, hardenability and the Jominy test, homogenization, and quenching and tempering treatments.

Heat Treatment and Assembly Operations in Tractor Gear-box Production. (*Machinery*, 1953, **83**, Dec. 18, 1197–1199). The article describes the heat-treatment and assembly of four- and six-speed gear boxes at the new factory of David Brown Tractors Ltd., The heat-treatment, which includes annealing, normalizing, carburizing, and tempering, is carried out in a battery of eleven 110-kW. Birlec electric furnaces. Checking and bench testing of the assemblies are discussed.

The Iron-Carbon Diagram. R. Whitfield. (*Machinery*, 1953, **83**, Dec. 25, 1253–1255). The article and accompanying diagram cover carbon contents from 1·5 to 4·3%. The annealing, quenching, tempering, and relieving of residual stresses in cast irons are discussed. Typical heat-treatment cycles for light and heavy castings involving the use of a carefully controlled decarburizing atmosphere are given.—M. A. K.

Surface Hardening of Tool Steels. J. Jech. (*Hutnické Listy*, 1953, **8**, (12), 619–622). [In Czech]. Surface-hardening of Poldi steel lathe tools with one and with two torches was studied. By a suitable adjustment of the distance between the burners, temperature distribution and cooling rates can be controlled to give a deeper, more regular hardening than with one burner only, and surface cracks are entirely eliminated.—P. F.

Induction Heating at Medium and High Frequencies. F. Makar. (*Elektrotehniški Vestnik*, 1953, **21**, (9–10), 249–256). [In Serbo-Croat]. The theoretical basis of high and medium frequency induction heating, covering the ranges 0·5–3 and 3–500 kilocycles/sec., is developed. The design of coreless induction furnaces for the surface treatment of metals, hardening of gear-teeth, soldering, and melting is discussed, and the appropriate frequency ranges, heat transfer, power output, primary-to-secondary current ratio, and efficiency, are determined. Rates of heat transfer 20 times higher than those obtained by flame-heating can easily be reached.—P. F.

High Speed Continuous Annealing of Tinplate. M. D. Stone and E. A. Randich. (*Iron Steel Eng.*, 1953, **30**, Oct., 69–75). After briefly describing the first methods employed for annealing tinplate, the authors discuss the relative merits of continuous and coil annealing. The authors show that, although costs are higher and products less reliable, the continuous process has definite advantages where several operations can be combined into a single continuous operation, *e.g.*, galvanizing and annealing.—M. D. J. B.

Modern Bell-Type, Bright-Annealing Furnace with Heat Recuperation. J. Arens. (*Draht., English Ed.*, 1953, Mar., 40–42). **Bright Annealing.** (*Metal Ind.*, 1953, **83**, Nov. 20, 423–424). An improved design of bright annealing plant for coils of strip is described. Four coil-stacking positions are provided ; these are arranged at the corners of a square. The stacks are covered with metal domes with a water seal at the bottom to hold the protective atmosphere. The heating cover is in a single unit with one resistance-heated chamber (*A*), two heat-exchanger chambers (*B* and *C*), and an open bay (*D*, diagonally opposite to *A*). *A*, *B*, *C*, *D* are spaced to fit over the four stacks, and *B* and *C* are connected by ducts with air-blowers. The annealing cycle is performed by raising the heating cover and turning it four times through 90° and lowering it at each new position for the required time. Thus, a fresh charge stacked in *D*, comes into a heat exchanger on the first 90° movement and is preheated by air circulated from the opposite exchanger chamber in which an annealed charge is cooling, while at the same time an already preheated charge is being annealed in *A*. An annealing installation, without heat recovery, with four stations in line consumed 235 kWH./ton with an annealing temperature of 700° C. An installation of the same capacity, of the new type with heat recovery was found to consume only 157 kWH./ton.—R. A. R.

Full Annealing of Low Alloy Steel Thick Forgings by Isothermal Transformation (I). K. Horikawa. (*Tetsu to Hagane*, 1949, **35**, Oct., 355–359 ; Nov., 378–381). [In Japanese]. Preliminary investigations with an alloy steel (C 0·30–0·35%, Mn 0·6–1·0%, Ni 1–1·8%, Cr 1·0–1·3%, Cu 0·2–0·4%, Mo 0·4%) showed that full annealing occurred within 4 hr. at 660–670°, 6 hr. at 650–680° or 9 hr. at 940° C. The microstructure was different from that after normal annealing, but mechanical properties after hardening and tempering were not affected. Isothermal annealing of a cylinder (450 cm. long, with outer and inner diameters of 66 and 48 cm.) was satisfactorily accomplished in a producer gas fired furnace, in half the time for normal annealing. Machinability was improved, and subsequent mechanical properties were not impaired.—K. E. J.

Possibilities of Relieving Residual Stresses. K. Wellinger. (*Schweissen u. Schneiden*, 1953, **5**, Dec., s157–s162). Several heat-treatments for relieving stresses in welds are investigated. Normalizing at between 550° and 650° C. will result in a change in structure and improvements in properties.—U. E.

FORGING, STAMPING, DRAWING, AND PRESSING

Forging Research—Use of Plasticine Models. P. M. Cook. (*Metal Treatment and Drop Forg.*, 1953, **20**, Nov., 541–548). The effect of tool width, reduction, and forging sequence, on the uniformity or otherwise of the deformation within forged material has been studied quantitatively in the B.I.S.R.A. (Sheffield) laboratories by making use of plasticine models. The technique for making multilayered models is described, and experiments are reported which indicate that plasticine is a satisfactory model for steel at forging temperatures. A stock-height to tool-width ratio of about 3 was found to produce the most uniform deformation in a simple slabbing operation. Curves showing the widely different types of strain distribution produced by various tool widths and reductions in cogging down operations are presented. The curves for multiple operations can be approximately predicted from simple indentation test results.—P. M. C.

Some Aspects of Theoretical Plasticity. A. P. Green. (*Metal Treatment and Drop Forg.*, 1953, **20**, Nov., 534–540). The mathematical study of stresses and strains in plastically deformed metal bodies commenced in the Mechanical Working Division of B.I.S.R.A. in 1948. In this brief survey, no attempt is made to cover the whole field of study, but some idea of the nature of the theoretical work is given with a few examples of the corroboration of theory by experiment. The idealized behaviour of a plastic-rigid material is discussed, and the mode of plastic yielding of such a body is compared with that of a similar real body. Practical applications of plastic-rigid solutions to sheet drawing, indentation by flat tools, extrusion, and notched-bar bending, are presented very briefly. (14 references).—P. M. C.

Co-operative Research in Metal Working. W. C. F. Hessenberg. (*Metal Treatment and Drop Forg.*, 1953, **20**, Nov., 525–526, 533). Events leading to the setting up of the new Metal Working laboratory of B.I.S.R.A. in Sheffield are briefly reviewed. The field of research—mechanics of deformation, metallurgy of deformation, friction and related phenomena between tool and work, design of tools, and design of plant—is outlined, and reference made to the large scale plant available.

Cutlery Research. C. N. Kington. (*Metal Treatment and Drop Forg.*, 1953, **20**, Nov., 563, 564). A brief outline is given of the activities and aims of the Cutlery Research Council, whose research team is housed on B.I.S.R.A.'s Sheffield site. There is close contact between the two organizations. Problems being studied include the composition and properties of cutlery stainless steel ; design, life, and defects of dies and tools ; mechanical aids to handwork, and instrumentation.

Sheffield Produces Record Hollow Forging. (*Metallurgia*, 1953, **48**, Dec., 276). A very short account of the production of a very large forged steel boiler drum is given. It is 42 ft. long and has an outside diameter of 6 ft. 2¼in. and an internal diameter of 5 ft. 6 in., and it was forged from a 153-ton billet. produced from a 217-ton ingot.—B. G. B.

Shaping and Production of Large Forgings. H. Gummert. (*Z. V.d.I.* 1953, **95**, Dec. 1, 1141–1145). The manufacture of large forgings is briefly described with notes on forge layout, ingot composition, structure, heat-treatment, typical forging operations, and the testing of finished forgings.—J. G. W.

Precision Forging of Gear Wheels by Czempiel's Method. H. Schumann and H. Böhme. (*Technik*, 1953, **8**, Dec., 817–820). An account is given of improvements made to the forging of bevel gears by a method introduced by A. Czempiel of the Kabelwerke Oberspree. In this method, gears are forged on a friction press with a dimensional accuracy of 0·004 in and little machining is required. The dies themselves are hobbed, and the gears are finished by coining.

New Axle Forge in the Ickles Works of Steel, Peech and Tozer. (*Rail Steel Topics*, 1953–54, **2**, 33–37). The layout,

equipment, and processes at this new forge are described. The plant, designed for an output of 100 axles per shift, includes a gas-fired continuous furnace 8 ft. 6 in. wide × 37 ft. 6 in. long, a 7-ton steam hammer with a 50 in. stroke, a coke-oven-gas-fired heat-treatment furnace 32 ft. long, a straightening press, a 5-ton hammer served by two gas-fired furnace for general forgings, and the necessary cranes and manipulators.

Further Progress in the Production of Valve Bodies by Forging, Welding, and Machining. K. Krekeler. (*B.W.K.*, 1953, **5,** Dec., 429–431). An account is given of several improvements in the design and manufacture of steel valves for use at high temperatures.—P. F.

The Use of Automatic Slide Feeds on Power Presses. J. L. Williams. (*Annual Proceedings of the Sheet and Strip Metal Users' Techn. Assoc.*, 1949–51, **4,** 11–16). This paper deals with the use of slide feeds on power presses in order to improve production with special reference to sheet and strip metal. Various feed mechanisms and their development are discussed.

Bending Thin-Wall Tubing. F. Pesak. (*Machinery*, 1954, **84,** Jan. 15, 129–133). Recent developments relating to the bending of thin-wall tubing for high pressure ducts of heating and ventilating systems manufactured by the North American Aviation, Inc., Los Angeles are described. It is shown how bending operations are carried out with flexible mandrels consisting of a series of interlocking spherical segments attached to a shank by a spring loaded cable.—M. A. K.

Die Design for Economical Production. P. Tobias and C. Erickson. (*Machinery*, 1954, **84,** Jan. 8, 55–61). The design of dies employed for the production of control instruments manufactured by the Minneapolis-Honeywell Regulator Co., Minneapolis, is described.—M. A. K.

Cold-Forming of Channels on a Vertical Hydraulic Press. R. Wagner. (*Machinery*, 1954, **84,** Jan. 1, 12–14). The author describes methods of cold forming the bends of structural channels 3 in. wide at the Crossley Division, Avco Manufacturing Corp. U.S.A. Bending, and the punching of holes in the rake frame with a multiple punching set-up, are carried out on a 750-ton vertical hydraulic press.—M. A. K.

Vickers-Armstrongs British Clearing 400-Ton Press. (*Machinery*, 1953, **83,** Dec. 25, 1251–1252). A description of a 400-ton single-action press supplied by Vickers-Armstrong Ltd., for use in the manufacture of motor cars is given.—M. A. K.

Cold Forging of Components from Wire and Strip—An Adaptable Geared Press. (*Engineering*, 1954, **177,** Jan. 1, 24–25). A geared press made by Taylor and Challen, Ltd. Birmingham, for forging a wide variety of components from wire and strip is described. It can produce 40 pieces/min. and exerts a maximum pressure of 120 tons.—M. D. J. B.

Practical Considerations Affecting the Fabrication and Mechanical Polishing of Stainless-Steel Sheet. D. H. Lloyd. (*Sheet Metal Ind.*, 1953, **30,** Sept., 767–774, 784). Stainless steel has certain peculiarities associated with its mechanical properties, surface finish, heat-treatment, and finishing methods which necessitate modification of the normal technique employed in the pressing, forming, and finishing of mild steel sheet. The author outlines, under the above headings, the pitfalls which await the unwary user working on 18/8 austenite steels.—P. M. C.

The Spinning of Stainless Steels. L. J. Hunt. (*Sheet Metal Ind.*, 1953, **30,** Sept., 779, 780, 783). A brief description is given of principles and practice in the spinning of stainless steel forms.—P. M. C.

An Evaluation of Spinning *vs.* Drawing. J. Lengbridge. (*Canad. Metals*, 1953, **16,** Sept., 36–40 ; Oct., 48–50 ; Nov., 36–40). The advantages and disadvantages of these two methods are considered and the types of operation which can be carried out are described. The economics of the two processes are discussed and examples showing the cost of articles produced by the two methods are given. Each process is suitable under certain circumstances and whether one or both are used depends primarily on the economics of each individual case.—B. G. B.

Making Hollow Steel Propeller Blades. (*Machinery*, 1953, **83,** Nov. 13, 939–947). The production and assembly of the outer shells for hollow steel blades at the Hatfield factory of De Havilland Propellers Ltd. are described. The shells are produced from 20 SWG nickel-chromium-molybdenum steel sheet. Details of the forming, welding, internal polishing, and testing are given.—M. A. K.

Problems of Sheet Metal Working. E. Siebel. (*Metall*, 1953, **7,** Dec., 970–973). Stresses and limiting deformations in sheet metal working according to elementary rules of plastic deformation are examined using the following examples : Cupping, deepdrawing by the ' hydroform ' method, redrawing, stretch forming, expanding of holes, pressing, and spinning.—J. G. W.

Shallow Shells Require Careful Die Design. S. R. Cope. (*Machinist*, 1953, **97,** Oct. 24, 1784–1786). The dies required for the production of shallow shells, and the system of ejecting from the press by means of a ' knock-out ' rod are discussed. Recommendations are made for the provision of holes or vents to release air trapped by the drawing action in order to prevent damage to both shells and dies.—M. A. K.

Layout of Deep-Drawn Shells Follows Certain Steps. S. R. Cope. (*Machinist*, 1953, Nov. 7, **97,** 1870–1873). The author describes how shell diameters can be reduced with each drawing operation, providing that the original grain structure is restored after every two or three draws by interstage annealing. The amounts of reduction for first-operation drawing dies, and, for successive redrawing dies, are tabulated for several metals.—M. A. K.

When You Redraw Shells Observe Certain Rules. S. R. Cope. (*Machinist*, 1953, **97,** Nov. 28, 1990–1993). The author discusses the use of single-action-push-through dies, inverted draw-collar dies for single-action presses and double-action dies. Important design aspects relating to redrawing dies are described.—M. A. K.

You Can Draw Rectangular Shells by Following Certain Rules. S. R. Cope. (*Machinist*, 1954, **98,** Jan. 30, 198–201). The author presents and explains some rules for the design of dies for drawing rectangular shells and points out certain differences in dies for circular and rectangular shells.—R. A. R.

Hidraw Deep-Drawing Presses. (*Machinery*, 1954, **84,** Jan. 8, 71–74). A 7000-ton hydraulic press constructed by the Hydraulic-Press Manufacturing Co., Ohio, is described. The machine is suitable for the ' Hidraw ' deep-drawing technique, which employs a combination of a rubber pad and an opposing hydraulic cushion. It is claimed that high quality surface finish, uniform wall thickness, and minimum of stretching are obtained.—M. A. K.

Impact Extrusion of High-Strength Aluminium. (*Machinist*, 1953, **97,** Oct. 31, 1819–1830). The design of dies for impact extrusion of high strength aluminium alloys is briefly discussed. Various types of tool steels, such as high-chromium high-carbon steel for the punch, and the necessary heat-treatment for the components of the dies are recommended. The factors determining the percentage reduction and the minimum cross sectional area for a given part are outlined.—M. A. K.

Containers for the Extrusion of Metals. H. M. Hiller. (*Metall*, 1953, **7,** Dec., 993–1000). Stress calculations, based on elementary theory of thick cylinders, are presented to show the advantages in terms of lower stresses and superior strength of multiple shrink-fitted containers. Various practical compound containers are examined, and a list of recommended steels is given. The less ductile the metal to be extruded the lower will be the radial pressure on container walls, in relation to punch pressure.—J. G. W.

How Crystal Structure Effects Metal Forming. S. Storchheim. (*Machinist*, 1953, **97,** Nov. 7, 1861–1869). The author defines the crystals structure of a metal, and the deformation of the structure which takes place during rolling, forging, wire drawing and similar operations that depend upon plasticity. The geometric relationship of the atoms within a crystal of element is discussed. The crystal systems and space lattices for various metals are tabulated.—M. A. K.

The Influence of Copper Content on the Deep-Drawability of Mild Steel Sheet. B. Otta. (*Hutnické Listy*, 1953, **8,** (12), 625–628). [In Czech]. An account is given of research into the deep-drawing, pressing, and tensile properties of a copper-bearing steel (Cu 0·98%, C 0·06%). If normalized, this steel has deep-drawing properties not noticeably different from ordinary, low-copper, deep-drawing steels, as shown by Erichson tests. When annealed, however, its drawability is less than that of low-copper steels.—P. F.

The Study of High-Speed Wire Drawing. J. G. Wistreich. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 530–533). High-speed wire drawing introduces technical problems in connection with heat generated by plastic deformation and by friction between wire and die. Both heat and lubrication are being studied with the aid of the new high-speed wire drawing machine in the B.I.S.R.A. laboratory at Sheffield.

A general assessment of the problems, and ideas for future work are presented.—P. M. C.

Core Wire for the Production of Extruded Metal Arc Welding Electrodes. W. I. Pumphrey. (*Australian Inst. Metals* 1953 *Symposium on Theory and Practice of Wiring Drawing*, Nov. 13, 1953, 25–26 ; *Wire Prod.*, 1953, **3,** Dec., 9–11). Chemical composition, surface quality, and dimensional accuracy of wire are discussed in relation to its use in the manufacture of extruded welding electrodes.—J. G. W.

Works-Designed Equipment Produces Wide Range of Drawing Dies. P. Trippe. (*Machinist*, 1954, **98,** Jan. 9, 49–51). The article describes the expansion of a powder metal section within Danite Hard Metals Ltd., into an individual plant specializing in the production of wire-drawing dies. The equipment used in hot and cold pressing operations, including furnaces and pneumatic presses, has been designed and built by the firm.—M. A. K.

Metallic Stearates for Wire Drawing. K. Schimz. (*Draht, German ed.*, 1953, **4,** Aug., 297). The author explains what metal stearates are, emunerates their merits as wire-drawing lubricants, and lists physical properties of aluminium, calcium, and lead stearate. He recommends lead stearate for alloy steels.—J. G. W.

The Story of Wire. R. R. Tatnall. (*Iron Steel Eng.*, 1953, **30,** Dec., 129–134). After a brief historical review of the manufacture of wire through the ages, the author discusses modern techniques with special reference to heat-treatment of steel wire.—M. D. J. B.

ROLLING-MILL PRACTICE

Plant and Equipment Installed in the (B.I.S.R.A.) Sheffield Laboratories. (*Metal Treat. and Drop Forg.*, 1953, **20,** Nov., 498–504). Descriptions are given of the major items of plant installed in the metal working laboratory and melting shop. These include : a Robertson 4-high cold rolling mill, with interchangeable work rolls 3½ in. to 7 in. in dia., which will roll a 4-ton coil of 12 in. wide strip at speeds up to 1750 ft./min. ; a small 2-high mill ; a cam-operated compression testing machine for determining stress-strain characteristics of steel at high speeds and high temperatures ; a 200-ton hydraulically operated forging press and forge furnace ; a two-hole, straight-line wire drawing machine by Marshall Richards, with many novel features and a top finishing speed of 5000 ft./min. ; a 10-cwt. EfCo arc furnace ; an induction, high-vacuum melting and casting equipment by Gerätebau-Anstalt Balzers. The major items of plant have been designed specially for research purposes, are unusually versatile, and have many instruments.—P. M. C.

Roll Force Measurement and Automatic Gauge Control. W. C. F. Hessenberg. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 527–529). The design of the B.I.S.R.A. industrial rolling load meter, based on the use of electrical resistance strain gauges, is briefly described. A method of using roll load measurements and screw positions to give the strip thickness is outlined, and the B.I.S.R.A. development from this of automatic control of gauge is briefly reviewed. (12 references).—P. M. C.

Strain Gauge Applications to United Equipment. J. I. Greenberger and R. H. Ellis. (*United Effort*, 1953, **33,** May-June, 8–12). The two types of instrument available for measuring roll pressure are discussed, and a detailed description is given of the magnetic type, with a 25 milliamp. output for a 0·002 in. movement of the air gap, which has been adopted by the United Engineering and Foundry Co. Circuit diagrams and some actual installations are shown.—R. A. R.

Roll Design. D. A. Winton. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 549, 550). The work of the B.I.S.R.A. Roll Design Conference is briefly outlined. It at present involves the collection of data on pass design for a particular section from each member of the Conference, whereupon reports are prepared by B.I.S.R.A. incorporating and comparing the data supplied. Much valuable information has been revealed concerning rounds, beams, angles, channels, and rails.—P. M. C.

Electrical Equipment for Reversing Cold Strip Mill. (*Electrical J.*, 1953, **151,** Nov. 27, 1763–1764). **Electric Drive of 14 in. Reversing Cold Strip Mill.** (*Engineer*, 1953, **196,** Dec. 4, 728–730). These articles describe the electrical equipment of the reversible cold strip rolling mill installed in the new B.I.S.R.A. Laboratories at Sheffield. The controls comprise fast and slow speed control, including emergency stopping, tension control, and speed limit.—M. D. J. B.

Design and Application of Bronze Slippers in Universal Couplings. J. R. Lottes. (*Iron Steel Eng.*, 1953, **30,** Dec., 123–128). The author describes the design and manufacture of bearing segments for universal couplings in rolling mills. Three methods of manufacture are examined : Sand cast bearing segments, three-piece segments, and permanent mould segments. The merits of phosphor bronze, silicon bronze, high tensile manganese bronze, aluminium bronze, and nickel-aluminium bronze are discussed.—M. D. J. B.

A Multi-Purpose Rolling Compound. M. L. Bible. (*Iron Steel Eng.*, 1953, **30,** Dec. 149). The author describes a new rolling lubricant which he claims can increase gauge reduction with a decrease in the subsequent cleaning requirements. The new lubricant also eliminates roll lubricants and emulsion cleaners on the rolls, dissipates heat, and increases roll life.

J. & L. Retires Steam-Driven Blooming Mill. (*Iron Steel Eng.*, 1953, **30,** Oct., 128–130). A description is given of the installation of an all electric drive in place of an old steam engine in the blooming mill of the Jones and Laughlin Steel Corp. The work was completed in eight days.—M. D. J. B.

Electrical Design and Operation of a Modern 46 in. High Lift Slabbing-Blooming Mill. G. A. Kaufman and A. W. Smith. (*Iron Steel Eng.*, 1953, **30,** Oct., 61–66). This article describes the fast electric drives of the new 46-in. slabbing mill at Jones and Laughlin Steel Corp., Pittsburgh. The main and auxiliary drives are rapid and are co-ordinated. A comprehensive system of spare and emergency equipment is a feature of this mill.—M. D. J. B.

Mechanical Design and Operation of a Modern 46 in. High Lift Slabbing-Blooming Mill. J. H. Mayer. (*Iron Steel Eng.*, 1953, **30,** Oct., 55–59). A description is given of the 46-in. slabbing-blooming mill recently installed by the Jones and Laughlin Steel Corp., Pittsburgh. Details are given of the mill layout, mill housing, spindles, motors, and soaking pits.

Blooming Mill Built for Detroit Steel. (*Iron Steel Eng.*, 1953, **30,** Nov., 140–150). The article describes a new two-high reversing high-lift 44 × 110 in. slab-blooming mill built for the Detroit Steel Corp. designed to produce 1,300,000 short tons/year of slabs and blooms. The slabs are to have a maximum width of 54 in. and the blooms are to range from 6 × 6 to 12 × 12 in. The maximum weight of slab ingot is to be 30,000 lb.—M. D. J. B.

The Various Qualities of Rolls and Their Use in Rolling Mills. W. Dornseiffer and W. Morgenstern. (*Met. u. Giesserei Techn.*, 1953, **3,** Sept., 378–380). An attempt is made to classify rolls according to their use in rolling mills.—L. J. L.

New Design of Repeaters Used for Small and Middle Section Bar Mill. N. Yoskitake. (*Tetsu to Hagane*, 1949, **35,** July, 223–225). [In Japanese]. Works studies are reported concerning the newly-designed oval and 'A.K.' repeaters, used respectively for mills producing bars 12–22 mm. in dia. and 50 × 50 mm. angles.—K. E. J.

Pass Design and Rolling of Automotive Rim Sections. H. H. Morgan. (*Iron Steel Eng.*, 1953, **30,** Dec., 55–60). The author describes roll pass designs for hot rolled wheel rim sections for heavy lorries and discusses the rolling techniques at the Jones and Laughlin Steel Corp.—M. D. J. B.

Automatic Equipment in Rolling Mills. A. N. Iroschnikow. (*Engineering News* (Moscow) 1948, (10), 5–19 ; *Met. u. Giesserei Techn.*, 1953, **3,** Sept., 367–375). This is a survey of recent developments in the U.S.S.R. to render rolling mills semi- or fully automatic. The main trends are towards simplification of machinery, individual drives for similar components, increased mechanization of working processes, incorporation of motors in the machines, increased range of electrical speed regulation, and electrical synchronization of speeds.—L. J. L.

Rolling Round Bars. W. Dornseiffer and W. Morgenstern. (*Met. u. Giesserei Techn.*, 1953, **3,** Nov., 480–481). Pass series for rolling rounds are discussed and the advantage of a new series, due to the first author, are pointed out. There are no diamond passes in this sequence, the intermediate passes being oval with the long axis alternately vertical and horizontal. The guides for this must be carefully made and a suitable design is shown.—R. A. R.

Different Stages in the Manufacture of Rails by Rolling. Stammbach. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1952, (11), 1583–1596). The production in Europe of rails from Bessemer steel is described and compared with American practice. Ingot size and form, blooming mill and finishing

train operation, and the various thermal treatments employed, are dealt with, together with straightening finishing, and acceptance tests.—A. G.

Evolution of Rail Sections. A. Petitfrère. (*Centre Doc. Sidér., Circ. Inform. Techn.*, 1952, (10), 1425–1451). A review of various roll pass designs is given, and the pass designs at seven works producing the same heavy rail section are discussed. The Bartscherer process is found to be useful for eliminating cracks in the rail foot when this zone contains blowholes, and a micrographic study of sections rolled in this manner is made.—A. G.

Wide Strip Mills—Evolution or Revolution. F. H. Fanning. (*Blast Furn. Steel Plant*, 1952, **40,** Aug., 913–920 ; *Amer. Iron Steel Inst., Yearbook* 1952, 194–221). *See* " Wide Strip Mill Opens World of New Ideas " *J. Iron Steel Inst.*, 1953, **173,** Apr., 445.

U.S.I.N.O.R., France's First Continuous Strip Mill. (*United Effort*, 1953, **33,** Jan.–Feb., 3–10). A well illustrated description is given of the new continuous strip mill at the Denain works of U.S.I.N.O.R. (Union Sidérurgique du Nord de la France).—R. A. R.

French Steel Company Installs Reversing Cold Strip Mill. (*Iron Steel Eng.*, 1953, **30,** Dec., 137–139). The article describes the new thin gauge cold strip mill of Société Etilam, Jeumont, France. Technical and operating data are given.

The Utilization of Large Steel Strip Mills. (*Usine Nouvelle*, 1953, **9,** Oct., 1 21–22 ; Oct. 8, 25–27 ; Oct. 15, 24–26). The evolution of continuous wide strip mills in America is described and the probable trends of this type of mill in West Europe are assessed. Sheet production is expected to reach 25 million tons in 1956, over 7 million tons coming from new continuous mills. The position in individual countries is briefly reviewed. The extension of cold rolling and the replacement of obsolete plant are discussed. A comparison of production costs and prices in America and Europe is made and the following conclusions drawn : (*a*) Lower European wages and social charges at present partially compensate the lower productivity ; (*b*) European works are smaller in general but new works are comparable with American ores ; (*c*) low tonnages and diversity of production hinder efficiency in Europe, hence a need for more standardization ; (*d*) sheet steel is relatively much cheaper in America and has risen less in price over the last 25 years than other products ; and (*e*) for heavy sheet and tinplate, continuous mills give better effieicncy. For thin sheet the efficiency is only slightly improved but quality is greatly superior.—A. G.

Comparative Tests on Strip Rolled by the Sendzimir Method. J. Teindl and A. Havlík. (*Hutnické Listy*, 1953, **8,** (12), 628–633). [In Czech]. The principle of the semi-continuous Sendzimir type strip mill, widely used in Poland, is explained. An account is given of a strip tinning plant utilizing the oxidation-reduction principle for the preparation of sheet surfaces before they enter the bath of molten tin. Comparative measurements of the sheet and coating thicknesses, as well as corrosion, microscopical, and chemical studies on sheet prepared by the Sendzimir method and tinned, and on similar sheet made by other methods are presented.—P. F.

Measurements of the Increase in Length During Cold Rolling. (*Mét. Constr. Mécan.*, 1953, **85,** Sept., 708–709). A short account of a method which employs Selsyn motors for measuring the increase in length of a strip during cold rolling, as in the skin pass technique, is given.—B. G. B.

Speed Regulation for Tandem Tube Mill Drives. (*Iron Steel Eng.*, 1953, **30,** Dec., 84–86). The article stresses the importance of maintaining proper speed relationships in the manufacture of seamless steel pipe by the stretch reduction process. Successful operation at the Lorrain Works of National Tube Co. shows that electronic control can be used under arduous conditions.—M. D. J. B.

Flying Shears for Billet, Bar and Rod Mills. J. H. Hitchcock and E. S. Murrah. (*Iron Steel Eng.*, 1953, **30,** Nov., 80–87). After describing early designs of flying shears, the authors discuss the principles adopted in modern designs and examine the electrical and mechanical problems involved. Layouts and circuit diagrams are given together with photographs of modern steam flying shears, electric crop and cobble shears, and rotating drum shears.—M. D. J. B.

MACHINERY FOR IRON AND STEEL PLANT

The Place of the Gas Turbine in Industry. T. J. Putz. (*Iron Steel Eng.*, 1953, **30,** Dec., 62–66). The author discusses the possibilities of using gas turbines as prime movers today in industry, and considers the applications of the three cycles in common use : Simple open cycle ; compound open cycle with regenerator ; compound open cycle with intercooler and regenerator. The possibility of using blast-furnace gas as fuel is considered and a 4500-kW. gas turbine power plant for electric power generation and a 125,000 cu. ft./min. air extraction gas turbine power plant are described.—M. D. J. B.

Flexible Connection Reduces Crane Runway Maintenance. J. A. Evans. (*Iron Steel Eng.*, 1953, **30,** Nov., 98–100). A new design is described for a flexible connection between the top of the crane runway girder and column. This connection holds the girder in line against the column by means of tie rods.

Truck Efficiency Test Tells When Corrective Measures are Needed. H. Milz. (*Iron Steel Eng.*, 1953, **30,** Oct., 143–146). The author sets a standard for fork truck efficiency and shows how this can be measured.—M. D. J. B.

Air Filters in Rotating Electrical Equipment Cooling Systems. F. C. Reutenauer. (*Iron Steel Eng.*, 1953, **30,** Nov., 71–76). The author reviews the factors which must be taken into account when choosing the proper type of air filter for motor rooms.—M. D. J. B.

WELDING AND FLAME-CUTTING

Resistance Welding: Research Progress by the B.W.R.A. H. G. Taylor and H. E. Dixon. (*Annual Proceedings of the Sheet and Strip Metal Users' Techn. Assoc.*, 1949–51, **4,** 82–97). The problem of mains voltage fluctuations is examined. A code of practice for the spot-welding of high-strength aluminium alloys and of steel is given. (15 references).—R. P.

Welding by Means of Condenser Discharge. F. Früngel and W. Thorwart. (*Z. V.d.I.*, 1954, **96,** Jan. 1, 18–21). In the process described the condenser is discharged through the primary winding of an impulse transformer. The energy required for welding is controlled by adjusting the charging potential and capacity of the condenser. Thus the energy supplied is substantially independent of the resistance of the workpiece. This is the chief advantage. Other advantages claimed are : High power factor, high energy throughput with consequent shortened welding time and reduced heating of workpiece outside weld. The design of suitable equipment is discussed and examples of welds between various metals are shown in 18 figures.—J. G. W.

Weldability of High Tensile Structural Steels. L. Reeve. (*Trans. Inst. Weld.*, 1953, **16,** Dec., 154–166). The development of weldable high-tensile structural steels is summarized, including the standard steels B.S.S. 548 and 968, and some of higher yield point. The steels referred to are those used for static structures such as steel-framed buildings and bridges, and mobile structures such as railway and road transport vehicles and ships.—U. E.

Application of Modern Metallurgy to the Welding of High-Tensile Steels. H. Lueb. (*Schweissen u. Schneiden*, 1953, **5,** Dec., s70–s73). The metallurgical properties of high-tensile steel were determined. Factors, such as alloying elements, structure and presence of hydrogen which affect the weldability of high-tensile steel, are discussed.—U. E.

Contribution to the Knowledge of Diffusion in Welding Processes. F. Erdmann-Jesnitzev. (*Schweissen u. Schneiden*, 1953, **5,** Dec., s89–s98). The diffusion of carbon and the decarburization of plain carbon steel is discussed. Micrographs are given showing the effect of heat-treatment and choice of electrode on the diffusion of carbon. The effect of chromium, nickel and manganese in the electrode coating and of nitrogen and hydrogen on the weld properties are investigated.—U. E.

Under-Water Welding. D. Brooks. (*Shipbuilder*, 1954, **61,** Feb., 105–107). A description is given of equipment and procedure for under-water electric welding, special attention being given to safety precautions.—R. A. R.

Welding Tool Steels. B. H. Chambers. (*Welding Metal Fab.*, 1953, **21,** Dec., 461–462). A brief history is given of welding high-speed steel tools. Flash butt welding is applied to attach the taper shanks of twist drills, end mills, and reamers. A modified atomic hydrogen welding process in which the carbon losses are controlled, is used to deposit high-alloy tool steel.—U. E.

Controlled Atmosphere Brazing of Stainless Steel Parts. (*Machinist*, 1953, **97,** Nov. 14, 1921). A technique for brazing

stainless steels in a standard furnace provided with a controlled atmosphere has been developed by the General Electric Co. Ltd. The process is claimed to be suitable both for copper-brazing stainless steels and for brazing components using 'Nicrobraz' alloy as the filler metal.—M. A. K.

Pipeline Distribution System of Industrial Gases and Medical Gas Installations. L. F. Roberts. (South African Inst. Welding : *Engineer Foundryman*, 1953, **18,** Dec., 45–55). The advantages of distributing oxygen and acetylene in pipelines in welding shops and laboratories are discussed and examples of installations are given.—A. D. H.

MACHINING AND MACHINABILITY

Engineering. C. N. Kington. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 565–567). The organization and activities of B.I.S.R.A.'s (Sheffield Group) workshop are described. A central design, machine shop, and maintenance section has been provided, which deals with nearly all apparatus construction and test specimen requirements of the research staff of the Steelmaking, Metallurgy, and Mechanical Working Divisions. Some examples of workshop products are illustrated.—P. M. C.

Study on the High-Speed Tools (VII). H. Hotta. (*Tetsu to Hagane*, 1949, **35,** May, 133–137). [In Japanese]. Investigations are reported on the relationship between machinability and angle of cut with 18–4–1 W/Cr/V standard high-speed steel. The influence of the viscosity and cooling velocity of liquids for cutting metals on the abrasion and machinability of the same steel was also studied.—K. E. J.

Improving the Fatigue Life of Springs by Liquid Honing. H. J. Steel. (*Machinery*, 1953, **83,** Dec. 4, 1083–1093). Liquid honing, which is a surface finishing process, consists of abrasives suspended in a liquid medium and the mixture is projected at high velocity on to the work by compressed air. It is shown that the process increases the fatigue resistance of springs considerably more than does shot peening. A description of the vapour blasting plant, the springs used, and the factors determining the liquid honing of large quantities under production conditions are given.—M. A. K.

Finish Rolling Cast Iron Guiding Surfaces for Machine Tools. W. Iwascheff. (*Machinery*, 1953, Nov. 27, **83,** 1058–1060). The author describes a method of finishing previously machined cast-iron guideways or bearing surfaces by a pressure rolling operation. A surface rolling attachment which may be employed on a planing machine or other suitable machine tool is illustrated. It is claimed that roll-finishing increases the useful life of the ways, reduces the coefficient of friction and lowers the rate of wear.—M. A. K.

Cool Tip, Not Chip, With CO_2. (*Machinist*, 1954, **98,** Jan. 2, 1–6). Progress in the use of CO_2 as a coolant for metal-working tools is discussed. Research by Carbon Dioxide Ltd., resulting in the development of a technique known as "CeDeCut" is described. The technique intensifies the cooling action of the CO_2 and eliminates the waste involved in needlessly cooling the chip. It is claimed that, experimentally, Nimonic 75 has been turned at 300 ft./min. and high-tensile steel at 950 ft./min.—M. A. K.

National Physical Laboratory Interferometer. D. C. Barnes and M. J. Puttock. (*Engineer*, 1953, **196,** Dec. 11, 763–766). This new interferometer uses a mercury-198 lamp as well as a cadmium lamp. The instrument is compact, convenient to use, and is for checking slip and block gauges up to 4 in.

M. D. J. B.

CLEANING AND PICKLING

Modern Aspects of Steel Pickling. G. de Lattre and A. De Lattre. (*Inst. Vitreous Enamellers Ltd., Bulletin*, 1953, **4** Nov.). A summary of present pickling techniques and spent pickle liquor treatment, with suggestions for future developments is made. (17 references).—R. P.

Introduction of Pickling Inhibitors into the Wire Drawing Shop. E. Dörling. (*Technik*, 1953, **8,** Dec., 821–823). The advantages of inhibitors are reported. It is shown that their use resulted in an improvement of mechanical properties of the wire ; the importance of the proper choice of acid concentration and temperature, and of pickling time, is stressed. Costs are examined.—J. G. W.

The Titration of Pickling Baths. G. Rossi-Landi. (*Mét. Constr. Mécan.*, 1953, **85,** Nov., 897). The preparation of a mixture of sand, caustic soda, and methyl orange for use in determining the acidity of an acid pickling bath, is described. A standard volume of the liquor is taken and known weights of the mixture are added until the solution becomes neutral.

Processing of Spent Sulphuric Acid Pickle Liquor. M. Puschner. (*Metall*, 1953, **7,** Nov., 896). An 'escalator' recrystallizing column is described, in which a counter current of air causes the sulphate to crystallize out whilst the liquor descends a zig-zag shaped pipe.—J. G. W.

Quality: The Key to Economical Use of Diamond Abrasives. C. R. Myer. (*Wire and Wire Products*, 1953, **28,** Nov., 1188–1191, 1231–1234). This review covers : Properties of diamond powder, origin and differences in quality of diamonds, diamond grading and the U.S. scale of prices, and cost analysis.—J. G. W.

Drum Smoothing and Polishing. (*Usine Nouvelle*, 1953, **9,** Nov. 5, 49–51). The parts to be treated are charged into a rotating drum with polishing agents, or with balls or rods, and a suitable abrasive. Polishing is in three stages, preliminary, finishing, and burnishing, the last being carried out in the absence of abrasives. Types of drum and the behaviour of the charge are discussed together with the influence of size, speed of rotation, and nature and volume of the charge. The choice between wet and dry tumbling and of equipment is considered.—A. G.

Metal Cleaning of Fine Instrument Components. E. A. Hedman and A. Miller. (*Metal Finishing*, 1953, **51,** Dec., 66–68). A laboratory evaluation of triethanolamine oleate for cleaning delicate mechanisms is described.—A. D. H.

Theory and Practice of Chemical Polishing. R. Pinner. (*Electroplating*, 1953, **6,** Oct., 360–367 ; Nov., 401–410). The author gives a review of published methods for polishing by immersion in aqueous solutions. Methods for copper, aluminium, zinc, cadmium, and steel are included. The economics of the process are briefly considered. (41 references).—A. D. H.

The Electrochemical Manipulation of Stainless and High-Duty Alloys. P. A. Charlesworth and C. Hobson. (*Sheet Metal Ind.*, 1953, **30,** Sept., 825–841). The many and varied uses of the electropolishing process both for surface finishing and for the removal of material to produce desired shapes or dimensions are described. Many illustrations demonstrate the applications of electropolishing to a wide variety of articles.

Theory of Electrolytic Polishing. R. Pinner. (*Electroplating*, 1953, **6,** Dec., 444–450). Theories of electrolytic polishing are reviewed. The liquid and solid film theories are critically compared. The influence of gas evolution-complex ion formation and operating conditions are discussed. (29 references).—A. D. H.

Electropolishing. (*P.E.R.A. Bull.*, 1954, **7,** Feb., 55–59). A very brief description of the electropolishing process is followed by a list of 57 references.—R. A. R.

A Non-Electrolytic Smoothing Treatment for Steel. W. A. Marshall. (*J. Electrodep. Tech. Soc.*, 1951–52, **28,** 27–45). The following solution gives a good polish to mild steel and whiteheart malleable iron : Oxalic acid 25 g./l., H_2O_2 13 g. l., H_2SO_4 0·1 g./l. Complete smoothing of ground textures of 40 and 20 μ in. was not achieved. Electrodeposited nickel adheres strongly to the treated steel. Steel smoothed in the solution becomes covered with a protective film which inhibits rusting. The method may be suitable for metallographic polishing.—A. D. H.

PROTECTIVE COATINGS

The Electrochemical and Electrometallurgical Industries of Canada. V. G. Bartram. (*J. Electrochem. Soc.*, 1953, **100,** Nov., 295c–302c). A general review is made of Canadian electrometallurgical industries giving details of products, location, and outputs.—A. D. H.

Growth of Parallel Grooves on Soluble Anodes by Electrolysis. T. B. Horiuchi. (*Metal Finishing*, 1953, **51,** Nov., 70–74). During high current, high voltage electrolysis, parallel grooves form on copper, brass, and iron anodes. The author's experiments show that the grooves are formed by bubbles of the same size which form on the lower parts of the anode, ascend, and sweep away smaller bubbles on the upper anode surface.

Effect of Impurities and Purification of Electroplating Solutions. I. Nickel Solutions. 7. The Effects and Removal of Chromium. D. T. Ewing, J. K. Werner, A. A. Brouwer, C. J. Owen, and W. O. Dow. (*Plating*, 1953, **40,** Dec., 1391–1400).

The effects of hexavalent and trivalent chromium on the appearance, adhesion, ductility, and corrosion resistance of nickel deposits have been determined in four different plating solutions. Ductility was lowered with Cr^6 whereas Cr^3 decreased salt-spray corrosion resistance. Adhesion was unaffected. High pH precipitation reduced the quantity of chromium to < 5 mg./l. if Cr^6 is first reduced to Cr^3. Deposition can be prevented by sufficient Cr^6.—A. D. H.

A Statistical Quality Control Approach to the Control of Plating Solutions. A. D. Woodell. (*Metal Finishing*, 1953, **51,** Dec., 54–58).

Temporary Protection Against Corrosion. (*Usine Nouvelle*, 1953, **9,** Oct. 22, 27–32 ; Oct. 29, 49–51). The required properties of protective agents, namely, ability to combat service conditions, ease of application and removal, and low price, are outlined. Such agents may be adherent like grease or wax, a peelable plastic covering, or a product generating an inhibiting vapour. The available agents and their range of usefulness are considered.—A. G.

Reflectivity Measurements for the Evaluation of Metal Surfaces. J. Elze and H. Gruss. (*Metalloberfläche*, 1952, **6,** Feb., A17–A23). An instrument for making the following determinations is described : (1) The light reflected at a given angle by a metal surface ; (2) the reflection within a selected angle ; and (3) the astigmatism of a scattered reflection. The instrument has high precision and gives reproducible results.—R. A. R.

The Use of Radio-Active Isotopes in Metallurgy. R. Shuttleworth. (*Brit. J. App. Phys.*, 1953, **4,** Nov., 326–329). The γ-radiation from radioactive isotopes is used for radiography, and the β-radiation for gauging the thickness of foils or, by back-scattering, the thickness of a coating on a base metal. The high sensitivity and ease with which isotopes can be detected and measured provide an easy method of estimating minute amounts of metal that have been labelled by pile irradiation. The most important metallurgical use of isotopes is in the measurement of self-diffusion coefficients.

An Optical Interference Instrument for the Measurement of the Thickness of Thin Metallic Coatings. M. Dühmke and K. G. Georgi. (*Metall*, 1953, **7,** Dec., 1000–1002). A method is described for measuring thicknesses in the range 10^{-3}–10 μ with an accuracy of $\pm$ 1 mμ, and particulars are given of an instrument designed for this purpose. Multiple interferometry is employed. The method is suitable for the measurement of thin metallic layers used in the study of the optical and electrical properties of metallic films.—J. G. W.

Development of the Chromizing Process. K. Daeves. (*Draht, English Ed.*, 1954, Feb., 30–32). This is an English translation of a paper which appeared in Draht, German Ed., 1953, **4,** Sept., 337–339 (*see J. Iron Steel Inst.*, 1954, **176,** Apr., 461).

Finishes Alternative to Conventional Nickel-Chromium. J. Chadwick. (*Electroplating*, 1953, **6,** Dec., 451–455). The corrosion resistance of substitutes for normal nickel–chromium plating was investigated in marine, industrial, and indoor conditions. A high-temperature chromium plating technique giving excellent results is described. Promising alternatives are tin–nickel and yellow bronze chromium-plated by the high temperature method.—A. D. H.

POWDER METALLURGY

Powder-Metallurgy Technique. (*Overseas Eng.*, 1954, **27,** Feb., 254–255). A short summary is given of advantages and limitations of the powder metallurgy process.—R. P.

Micro-Powders Provide Permanent Magnets with New Properties. (*Machinist*, 1953, **97,** Dec. 12, 2088–2093). The article describes the production in England of permanent magnets of entirely new type made from soft ferromagnetic metal powders. They are moulded from extremely fine powders of iron or iron alloys, known as micro-powders, which derive their permanent magnetic properties solely from the fineness of their particle or crystal size. Production is simplified, and shafts, pole pieces, or inserts can be included in the mouldings.—M. A. K.

Developments in Sintered Magnetic Materials. J. L. Salpeter. (*J. Brit. Inst. Radio Eng.*, 1953, **13,** Oct., 499–515). The fundamental principles of ferromagnetism are recalled, followed by a discussion of the principles which guided the development of modern non-metallic magnetic materials. The basic reasons for the properties of "Ferroxcube" (derived from magnetite) and "Ferroxdure" (derived from magnetoplumbite $PbO.6Fe_2O_3$) are explained.—R. P.

The Production of Powdered Iron Cores. E. Istvanffy. (*Magyar Hiradastechnika* (Budapest), 1952, (1–2), 2–8 ; *Met. u. Giessereitechn.*, 1953, **3,** Oct., 439–443). The author discusses the essential properties of powdered iron cores, various types, methods of production, possible substitutes, and a new Hungarian process for the production of iron powder and powder cores.—L. J. L.

Methods of Quality Control for Sintered Carbides. S. Blažek. (*Hutnické Listy*, 1953, **8,** (12), 622–625). [In Czech]. Methods of measuring the hardness and porosity of sintered carbide tool-tips are discussed. A metallographic analysis based upon high-magnification microscopy is recommended. A simple method of preparing specimens for the microscope, which requires very little diamond dust, is described.—P. F.

Modern Metal Powder Industry. R. L. Ziegfield. (Amer. Soc. Tool Engineers : *Canad. Metals*, 1953, **16,** Nov., 54–56). A brief review of the manufacture and use of small parts made by the powder metallurgy method, is given.—B. G. B.

PROPERTIES AND TESTS

Determination of the Bursting Pressure of a Vessel from the Characteristics of the Metal in Tension. H. de Leiris and P. Bastien. (*Rev. Mét.*, 1953, **50,** Oct., 683–696). After recalling that, in the absence of premature failure, the bursting of a cylindrical vessel under pressure is a type of static failure related to the tensile strength, the calculation of critical pressure from the theory of plasticity and the rational stress-strain curve is described. The results of controlled experiments agree with those obtained by this calculation within 2–4%.—A. G.

Relation between the Exact Form of the Tensile Curves for Metals and the Accompanying Modifications in Their Structure. C. Crussard. (*Rev. Mét.*, 1953, **50,** Oct., 697–710). The detailed tensile curve for polycrystalline materials consists of two parabolic sections with a transition point corresponding to grain fragmentation. Equations are proposed enabling the elongation before necking to be predicted. With single crystals, deformation bands (dependent on orientation) affect the stress-strain curve. The analogy between such deformation bands and the fragmentation of polycrystalline samples at the transition point is discussed and a theoretical explanation is put forward.—A. G.

Methods and Machines for Testing Materials (Impact Tests). M. C. Boulet. (*Usine Nouvelle*, 1953, **9,** Sept. 17, 29–32 ; Sept. 24, 49–55 ; Oct. 15, 49–55 ; Oct. 22, 49–51). Impact tests measure the energy absorbed at a variable speed of rupture and entail either rapid bending or occasionally shock tension (extension speeds greater than 1 m./sec.). An historical review of the development of impact tests is given. In notch impact tests the material is tested under triaxial stress. The relative values of decohesion and slip may be determined at various temperatures and the temperature of transition to brittleness may be used for steel specification. The use of available impact testing machines is described.

The Tendency to Brittle Fracture—Decisive Problem in the Performance of Welded Structural Steels. A. Legat. (*Radex Rundschau*, 1953, July (6), 27–35). It is shown that the tendency of steels to brittle fracture depends upon the properties of the particular steel and external conditions affecting the limit of plastic deformation. The author finds that present methods of predicting this tendency are inadequate.

Free Surface Motion Induced by Shock Waves in Steel. W. A. Allen. (*J. App. Phys.*, 1953, **24,** Sept., 1180–1185). An optical technique has been used to measure surface oscillations on a series of steel plates $5\frac{1}{2}$ in. in dia. of different thicknesses while they deform under explosive attack. Data from six specimens of 0·25% carbon steel have been partially analysed and compared with the theory of elasticity.—J. O. L.

Some Notes Concerning Electrical Resistance Strain Gauges and Their Applications. W. C. Heselwood. (*Rail Steel Topics*, 1953–54, **2,** Winter issue, 23–32). The principles of resistance strain gauges are briefly stated and their method of use is outlined. Several applications under both static and dynamic conditions of loading are given.—A. D. H.

Plastic Deformation of Metals—Survey of Literature 1950–1951 Inclusive. (*Amer. Iron Steel Inst. Contributions to the Metallurgy of Steel No.* 42, Dec., 1952). This 257-page publication contains classified abstracts of papers from the world's technical literature on plastic deformation, published in 1950 and 1951, together with an author index.—R. A. R.

On the Use of Hodographs in Problems of Plane Plastic Strain. A. P. Green. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 73–80).

Calculations and Measurements on Wedge-Indentation. J. Grunzweig, I. M. Longman, and N. J. Petch. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 81–86).

The Plastic Torsion of Anisotropic Bars. R. Hill. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 87–91).

Impact of Finite Beams of Ductile Metal. P. S. Symonds and C. F. A. Leth. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 92–102).

On Eulerian Co-Ordinates in Elastic Wave Propagation. R. E. D. Bishop and J. N. Goodier. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 103–109).

On Inoue's Hydrodynamical Analogy for the State of Stress in a Plastic Solid. R. Hill. (*J. Mech. Phys., Solids*, 1954, **2**, Jan., 110–116).

Shells with Zero Bending Stresses. M. R. Horne. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 117–126).

On the Stress Distribution in the Walls of Pressure Vessels. H. Fessler and R. T. Rose. (*J. Mech. Phys. Solids*, 1954, **2**, Jan., 127–136).

A Theoretical Calculation of the Stored Energy in a Work-Hardened Material. A. N. Stroh. (*Proc. Roy. Soc.*, 1953, **218A**, July 7, 391–400). The amount of energy stored in a cold-worked material is calculated on the assumption that the energy is due to piled-up groups of dislocations. It is found that a small percentage of the work done in deformation is stored, and that the amount of energy stored is proportional to strain. These predictions are in reasonable agreement with experimental results.—R. A. R.

Determination of the Surface Stress by Means of Electroplating. H. Okubo. (*J. App. Phys.*, 1953, **24**, Sept., 1130–1133). By the use of specimens plated with copper, the stress is measured by variation in the appearance of flecks which is due to the change of load under cyclic stress. Experimental results are in good agreement with theory.—J. O. L.

Relief and Control of Residual Stresses by Flame Heating. M. Pfender. (*Schweissen u. Schneiden*, 1953, **5**, Dec., s62–s69). The fundamental principles which control the formation and stability of residual stresses are discussed. Data on the influence of the properties of the material, temperature, strain, and stress conditions on plastic deformation, and the use of flame heating for relieving residual stresses are reviewed. (25 references).—U. E.

Critical Survey of Shrinkage Stresses, Their Origin, Measurement, and Effect on Safety. R. Weck. (*Schweissen u. Schneiden*, 1953, **5**, Dec., s141–s150). The fundamental difficulties of defining stress conditions and the determination of stresses are described. The influence of shrinkage stresses on static loading capacity, deformation, and brittle fracture, and their effect on corrosion and endurance limit are discussed.—U. E.

The Influence of Shrinkage Stresses on the Strength of Metal Structures. M. Pfender. (*Schweissen u. Schneiden*, 1953, **5**, Dec., s150–s156). The origin and distribution of shrinkage stresses in welds and their effect on the mechanical properties of steel structures are discussed.—U. E.

Shear under Tension or Compression. A. Coüard. (*Genie Civil*, 1953, **130**, Dec. 1, 453–454). Established theories cannot explain the different types of failure under tension and compression. A new hypothesis is discussed and tests suggested for determining the relative values of intragranular shear and intergranular adhesion.—A. G.

Observations on Parts Cracked or Broken in Service. (Crankshafts, Helical Springs, etc.). P. Coron. (*Rev. Mét.*, 1953, **50**, Oct., 711–726). Several dozen failed crankshafts and other parts have been examined in the laboratories of Aciéries de la Marine at Saint-Chamond. In all cases crankshaft failure was due to fatigue mainly at the inside of the joints between the web and cylindrical part of the shaft. Flaking, welding repairs, and residual stresses may promote cracks.

Contribution to the Explanation of the Mitigating Effect in Fatigue Stressing. H.-O. Meuth. (*Metall*, 1953, **7**, Dec., 974–977). The fatigue limit of notched specimens is higher than that calculated from the stress concentration in the notch. The author distinguishes between an apparent improvement, which is the outcome of the adopted method of calculation, and the real improvement which appears to be a function of the stress gradient. Various hypotheses concerning the cause of the latter are examined.—J. G. W.

Fatigue Properties of Steels. J. Clayton-Cave and E. Ineson. (*Metal Treatment and Drop Forg.*, 1953, **20**, Nov., 553–556). Brief details are given of a comprehensive investigation, of the effect of inclusions on the fatigue properties of En 19, 24, and 100 steels, which is to be undertaken by B.I.S.R.A.'s Metallurgy (General) Division. Twelve fatigue testing machines of the two point loading, rotating bending type have been installed, and the first part of the investigation, designed on a statistical basis, involves some 2000 specimens. The importance of test-piece design, dimensions, and surface finish are stressed, and methods employed to keep them uniform within reasonable limits are outlined.

Some Notes on Fatigue in Grey Cast Irons. O. Puchner. (*Slévárenství*, 1953, **1**, (7), 170–176). [In Czech]. The behaviour of cast irons under fatigue stresses in torsion, tension-compression and bending is discussed with reference to the metallurgical structure and the dimensions of the specimens.

Hardness of Solids. D. Tabor. (*Endeavour*, 1954, **13**, Jan., 27–32). A physical explanation of Mohs scratch-hardness, based on the relation between the indentation hardness of a metal and its plastic yield stress is presented. (14 references).—R. P.

On the Reappearance of Sharp Yield Point of Mild Steel by Aging. R. Hasiguchi. (*Tetsu to Hagane*, 1949, **35**, Sept., 296–302). [In Japanese]. The increases in yield point and tensile strength of mild steel during strain-ageing are examined and expressed mathematically. Velocity constants and activation energies are derived. It is suggested that precipitation in the grain boundary skeleton and inside the grains follows the same pattern. (13 references).—K. E. J.

High Permeability Alloys in the System Ni–Fe–Cu–Mo. F. Assmus and F. Pfeifer. (*Metall*, 1953, Mar., 189–191; *Iron Steel Inst., T.M.S.* 210, 1954). The influence of an annealing treatment in the temperature range 300° to 600° C. on the magnetic properties was tested on a series of copper-bearing Permalloy alloys. It was found that the high permeability values appearing in Supermalloy after certain critical tempering treatments are not confined to this alloy, but that a whole series of alloys with similar favourable properties exist. The resistance anomaly present in Supermalloy appears also in copper-containing alloys.—R. A. R.

Applications of Calorimetry, with Reference to Magnetic Steels. K. L. Morphew. (*British Assoc.: Engineering*, 1953, **176**, Dec. 11, 765). The author refers to a calorimetric method in which the alternating magnetization of an iron specimen produced heat which was shared by all parts of the calorimeter and its fluid surround, and then to describe a new method in which the specimen does not share its heat with a calorimeter and cooling fluid, but acts as its own calorimeter. (12 references).—M. D. J. B.

Development and Status of Soft Magnetic Materials. H. Fahlenbrach and W. Heister. (*Stahl u. Eisen*, 1953, **73**, Dec. 3, 1644–1652). The development and properties of pure iron, iron–nickel, nickel–molybdenum, iron–cobalt–vanadium, and oxidic materials are discussed. The oxide magnets (ferrites) throw new light on the phenomenon of ferromagnetism.—J. P.

An Automatic Plotter for Magnetic Hysteresis Loops. H. McG. Ross. (*Inst. Electrical Engineers Preprint* M1637, Dec. 20, 1953).

The Effect of Tension on the Thermoelectric Properties of Metals. A. J. Mortlock. (*Australian J. Physics*, 1953, **6**, Dec., 410–419). Measurements have been made on 11 metals of the change in thermoelectric power accompanying elastic tensile strain in the temperature range 20–400° C. There is evidence that the magnitude of the general effect is dependent upon the purity of the specimen. On annealing iron, the e.m.f. became predominantly positive and non-linear in its relation to stress, at constant junction temperatures. The e.m.f. generally increased as the load increased, reached a maximum, and then decreased.—R. A. R.

The Non-Destructive Testing of Wire by Means of Ultrasonics. R. Pohlmann. (*Draht. English ed.*, 1953, Dec., 24–26). The application of the Sonometer transmission method of ultrasonic flaw detection to wire and wire products is described.—J. G. W.

Contribution to the Theory and Practice of Ultrasonic Testing. H. J. Seemann and W. Bentz. (*Metall*, 1954, **8**, Jan., 1–11). The authors discuss: The influence of structure on the extinction of elastic waves; apparatus and methods used; ultrasonic, X-ray, and gamma-ray examinations of coarse

structure ; ultrasonic examination of sheet metal and small parts, inclusions, and segregations.—J. G. W.

Ultrasonic Testing of Materials and Particularly the Testing of Welds. E. Martin and K. Werner. (*Schweissen u. Schneiden*, 1953, **5,** Dec., s74–s81). The ultrasonic testing methods are described. The method of impulse transmission time is discussed in detail showing the effect of perpendicular and inclined transmission. Ultrasonic, X-ray, and micrographical examination of welds are compared.—U. E.

Ultrasonic Testing of Round Steel Bars for Internal Defects. H. G. Brandt. (*Stahl u. Eisen*, 1953, **73,** Dec. 17, 1717–1720 : *Iron Steel Inst. Translation Series No.* 484, 1954). Round bars of high-speed steel, 30 to 90 mm. in dia., have been tested by a transverse impulse-echo method. The type of internal defect and its size can be judged from the image on the cathode-ray screen. With bars from 30 to 40 mm. in dia., it is difficult to gauge the size of defects, and with diameters from 50 to 60 mm. the accuracy of size determination, from the ratio of the defect echo to the base echo, is a maximum.—J. P.

New Instruments for the Optical Recording of Mechanical Vibrations. H. Freise. (*Z.V.d.I.*, 1954, **96,** Jan. 1, 22–26). Two instruments are described, one for vibrations of small amplitude, the other for large amplitudes. The former has a natural frequency of 5 cycles with small amplifications and 14·4 cycles with large amplifications, the damping factors being 0·32 and 0·09 respectively.—J. G. W.

Union Firms Using Non-Destructive Testing Equipment. (*Engineer Foundryman*, 1953, **18,** Nov., 47–91). Descriptions are given of the plant and methods of three South African firms using X-rays, gamma rays, and ultrasonic methods of testing.—A. D. H.

Non-Destructive Testing in South Africa. D. J. Stern. (South African Inst. Welding : *Engineer Foundryman*, 1953, **18,** Oct., 67–81). A brief review is given of non-destructive testing in welding and of X-ray, gamma ray, ultrasonic, magnetic, and pressure leak methods.—A. D. H.

Progress Report on Mechanical Properties of Binary Alloyed Ferrites at Low Temperatures. G. A. Moore and H. T. Green. (*Amer. Iron Steel Inst. Contributions to the Metallurgy of Steel No.* 34, June 1949). A successful vacuum method for producing practically pure binary ferrites is described and the preparation of a relatively pure 0·2% aluminium ferrite is outlined. The procedure and equipment for testing specimens of this ferrite at temperatures in the range +100° to −192° C. are given. The binary aluminium ferrite tested was fairly ductile at down to −100° C. with a marked decrease at lower temperatures and almost no ductility at −192° C.

Metals for Extreme Temperatures. M. M. Hoover. (*Chem. Eng.*, 1953, **60,** June, 212–215). The selection of metals for high and low temperature service is discussed in relation to the problems of creep and embrittlement, respectively.—A. G.

On the Validity of Mott's Theory of the Beta-Flow in Polycrystals. P. Feltham. (*Phil. Mag.*, 1954, **45,** Jan., 9–12). A survey is given of the experimental evidence concerning the activation energy for transient creep. The Andrade equation may be written in a form in which the dependence of a factor on stress and temperature is governed by the same constants as for steady state creep. With certain qualifications, Mott's statistical theory appears to be a correct interpretation. (11 references).—K. E. J.

Influence of Composition and Structure on Creep Resistance. J. Hochmann. (*Bull. Cercle Etudes Mét.*, 1953, **6,** Mar., 117–147). A detailed review of the influence of composition and structure on the resistance to creep of carbon steels, ferritic alloy steels, austenitic alloy steels of the 18/8 type, and modern ' super alloys ', is presented. (24 references).—B. G. B.

Special Steels for the Petroleum Industry. E. Smith. (*Chem. Indust.*, 1953, Aug. 10, s9–s17). The properties and uses of high-nickel, high-chromium steels for corrosion and heat-resisting purposes are discussed and heat-treatment procedures and stabilizing additions are considered.—J. O. L.

Pipe Flanges Research Committee Third Report. A. E. Johnson. (*Inst. Mech. Eng., Advance Copy*, Feb. 12, 1954). This Third Report presents the results of investigations into the elastic and plastic (creep relaxation) behaviour carbon steel and molybdenum steel flanges, drilled and undrilled, by means of model flanges, and of certain bolt materials. In an addendum by R. W. Bailey reference is made to using the results of the investigations to meet engineering requirements.

Report on the Elevated Temperature Properties of Chromium Molybdenum Steels. W. F. Simmons and H. C. Cross. (*Amer. Soc. Test. Mat. Spec. Tech. Pub. No.* 151, 1953). This report contains about 200 pages of graphs and tables depicting the tensile strength, 0·2% proof stress, elongation, reduction in area, stresses for rupture in 100, 1000, 10,000, and 100,000 hr., Larson-Miller parameter curves, and stresses for creep rates of 0·001 and 0·0001%/hr., at high temperatures, for a large number of Cr–Mo steels.—R. A. R.

High Alloy Castings Resist High Temperatures. (*Iron Steel Eng.*, 1953, **30,** Oct., 130, 134, 138). The three main heat-resisting alloys (iron–chromium, iron–chromium–nickel, and iron–nickel–chromium) are briefly described. Examples show how these alloys provide various combinations of mechanical properties and resistance to corrosion by hot gas.

The Properties of Some Heat-Resisting Steels at High Temperature. M. Tagaya and S. Isa. (*Tetsu to Hagane*, 1949, **35,** Nov., 393–397). [In Japanese]. Variations in properties of Fe–Cr and Fe–Cr–Al alloy wires at temperatures up to 1200° C. are reported.—K. E. J.

Study on the Hot Die Steels. K. Deguchi and S. Watanabe. (*Tetsu to Hagane*, 1949, **35,** Nov., 382–393). [In Japanese]. Studies were made at various temperatures of the mechanical properties of low-carbon steels alloyed with various combinations of tungsten, chromium, vanadium, nickel, and molybdenum.—K. E. J.

Aspects of Research Involving High Temperatures. V. H. Stott. (*Research*, 1953, **6,** Dec., 454–457). The problems of research at temperatures above 1500° C. are outlined, and available techniques, furnace equipment and refractories are discussed.—K. E. J.

On the Effect of Each Element on the Low W–Cr Tool Steel for Hot Work. S. Koshika. (*Tetsu to Hagane*, 1949, **35,** Oct., 345–349). [In Japanese]. Tool steels for hot work containing 5–6% of tungsten are superior to those containing 9–11%. The optimum composition for low-tungsten steel is C 0·25–0·35%, Cr 2·5–2·8%, W 5–7%, and V 0·4–0·5%.

Study on the Tool Steel for Hot Working. S. Koshiba and S. Nagashima. (*Tetsu to Hagane*, 1949, **35,** July, 211–214). [In Japanese]. The optimum amount of tungsten is 6–8% for a tool steel for hot work containing 0·26–0·33% C, 2·5% Cr, and 0·3% V.—K. E. J.

Study on the Silichrome-Tungsten Heat-Resisting Steels. K. Deguchi. (*Tetsu to Hagane*, 1949, **35,** June, 176–185 ; July, 207–211). [In Japanese]. Results of measurements of the transformation points, tensile properties and impact values at room and high temperatures show that the molybdenum of Si–Cr–Mo steels may be replaced by the same amount of tungsten, and the silicon content may be lowered. By deoxidation with aluminium or titanium and reducing the grain size, the grain growth, coarse fracture and lowering of impact value in Si–Cr–W steels after over-heating may be reduced. The influences of nickel, copper and tin on mechanical properties at various temperatures were studied. It is better to reduce the chromium content from the normal 12–15% to approx. 9–11%, to prevent lowering of the room and high temperature impact values, and to economize in chromium.—K. E. J.

Creep Tests in Inert Atmospheres. A. J. Fenner and G. Willoughby. (*J. Sci. Instruments*, 1953, **30,** Nov., 406–407). An apparatus is described for conducting creep tests in a gas chamber which can be filled with argon. The extensometers, of the rhomb and mirror type, are totally enclosed in the chamber, and the mirrors are adjusted, reset and tilted during the test by plungers passing through rubber glands into the chamber.—L. D. H.

High Temperature Test Data and Their Importance in Design. H. C. Cross. (*Product Eng.*, 1953, **24,** Oct., 182–187). Rupture and creep tests combined to show the relation between stress and time for rupture, transition point, the various amounts of total deformation at a fixed temperature are described in their relationship to design. The effects of deformation and cyclic loading and variations in batches of material are also discussed. Stress/total-deformation curves for several heat-resisting, alloy sheet materials (high nickel–chromium alloys) under load for 1 min. are also given.—A. M. F.

Studies on the Flake-Like Defects in Steel. IV—Effects of Oxygen. V—Acid Pickling of Special Structural Steel. Y. Shimokawa. (*Tetsu to Hagane*, 1949, **35,** Apr., 104–110 ; May, 128–133). [In Japanese]. Statistical analysis shows no correlations between flake appearance and oxygen content, non-metallic inclusions, or nitrogen content. No distinct variation of flakiness occurs as oxygen-rich material is added,

although hydrogen evolution at high temperatures increases. Increasing additions of aluminium or ferrotitanium remove flakiness, due to the variation of steel properties. The effect of oxygen is therefore thought to be an indirect factor. In medium-carbon low-alloy steels pickled in H_2SO_4 solution saturated with FeS, flake-like defects were found after fracture in tensile and bending test pieces. Various conditions are described. The defects are attributed to the combination of hydrogen supersaturation and mechanical stress.—K. E. J.

Work of the Metallurgy Division. M. L. Becker. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 551, 552). This B.I.S.R.A. Division's field of activity, which concerns the provision of background information on the effects of composition, structure, and treatment upon the physical and mechanical properties of steels, is very briefly outlined.

Researches on Pure Metals. G. M. Leak, A. M. Sage, and E. Ineson. (*Metal Treatment and Drop Forg.*, 1953, **20,** Nov., 557–559, 562). A brief outline is given of several investigations, using pure iron with controlled amounts of alloying elements and/or impurities, which are being undertaken by the B.I.S.R.A. Metallurgy (General) Division in the new Sheffield laboratories. The work includes the study of the effects of nitrogen and carbon on the strain-ageing characteristics of pure iron, and the effect of impurities on the permeability of pure silicon-iron sheet.—P. M. C.

How to Understand Alloy Steels. S. Storchheim. (*Machinist*, 1953, **97,** Oct. 24, 1773–1782). The major changes in the mechanical properties of steel caused by the addition of alloying elements and the effects upon chemical inertness are described. Alloy characteristics such as tensile strength, yield strength and heat-treatment for various alloy steels containing nickel, tungsten, molybdenum, and manganese, are discussed.—M. A. K.

Boron Steels. G. Delbart. (*Bull. Cercle Etudes Mét.*, 1953, **6,** Sept., 165–200). A comprehensive account of the manufacture and properties of boron steels is presented. The transformation curves of different boron steels are considered. Details of Amer. Iron Steel Inst. boron steels and of a number of normal steels with their boron steel substitutes are given. A short review of British, German, and French research work on boron steels is made. (35 references).—B. G. B.

How Boron Enhances the Hardenability of Steel. T. G. Digges. (*S.A.E. J.*, 1953, **61,** Sept., 24–27). The effectiveness of boron appears to be due entirely to its action while in solid solution in austenite, which is to decrease the rate of nucleation and not the rate of growth of ferrite and carbide. A fair amount is now known about the action of boron in steel, and the author reviews the relevant literature. Some recent work by the author on the influence of nitrogen in boron-treated steels, and on the diffusion of boron in austenite is described. (12 references).—P. M. C.

High Strength Weldable Structural Steel with Aluminium and Titanium Additions. R. Mitsche and A. Legat. (*Stahl u. Eisen*, 1953, **73,** Dec. 3, 1652–1654). Investigations in the laboratory and in the field have shown the suitability of aluminium and titanium as nucleating agents for improving the mechanical properties of manganese structural steels. By appropriate steelmaking conditions, such steels can be produced with high yield-point/tensile-strength ratio and good deformability and resistance to brittle fracture.—J. P.

A Review of the Effects of Titanium and Zirconium in Steel. L. C. Bogan. (*Australasian Eng.*, 1953, July 7, 51–55). The author stresses that the practical functions of titanium and zirconium are associated with the strong chemical affinities these elements have for oxygen, nitrogen, carbon, and sulphur. Two broad divisions arise within the commercial uses of the elements in steel manufacture. One is concerned with deoxidation and scavenging generally, the other relates to their true alloying properties which are all related to carbide stabilization. The whole subject is discussed in general terms.—P. M. C.

The Effect of Aluminium Additions on Steel in a Small Acid Converter. (*Fonderie*, 1953, Aug., 3569–3570). A brief account is given of the effect of aluminium additions on the inclusion distribution and mechanical properties of acid converter steels. The results agree with those obtained by Sims and Dahle for induction melted steels, and show that, with increasing residual aluminium from 0·002% to 0·1%, the elongation decreased as a grain boundary distribution of inclusions was produced.—B. C. W.

17% Chromium Stainless Steel . . . an Effective Replacement for Hard-to-Get Nickel-Bearing Stainless. (*Machine Design*, 1953, **25,** June, 118–122). The corrosion resistance, mechanical properties at low normal and high temperatures, magnetic properties, and weldability of the free-machining and welding qualities of 17%-Cr stainless steel are compared with those of 18/8 Cr–Ni steels. The chromium steel is not recommended for low temperature service where impact resistance is required and it has a tendency to become brittle at room temperature after prolonged service in the 800–1000° F. range. Welded joints in the 17%-Cr steel are somewhat brittle at room temperature when no titanium is present, but with titanium the welds are fairly ductile in both the as-welded and annealed conditions.—R. A. B.

On the Mechanical Properties of the High Mn–Cr Heat-Resisting Steels (I). (Study on the Heat-Resisting Steels IV and V). K. Deguchi. (*Tetsu to Hagane*, 1949, **35,** Sept., 305–312 ; Oct., 349–355). [In Japanese]. An investigation of various heat-treatment processes was made for Mn–Cr–V steels. The influences of carbon, nickel, tungsten, molybdenum, vanadium, titanium, and copper on steel properties after various heat-treatments were ascertained.—K. E. J.

Ultra High Strength Steel for Aircraft Structures. M. A. Melcon. (*Product. Eng.*, 1953, **24,** Oct., 129–141). Comprehensive tests by Lockeed on a Cr–Ni–Mo steel are described. The steel was heat-treated to strength levels of 260,000–280,000 lb./sq. in. and was shown to be suitable as an aircraft structural material. Tests were to determine the static, impact, and fatigue properties, notch sensitivity characteristics, and the fabricating and processing techniques including machining, welding and finishing.—A. M. F.

Repeated Impact Tests on Plain Carbon and Si-Mn Spring Steels. K. Shinji. (*Tetsu to Hagane*, 1949, **35,** Nov., 397–401). [In Japanese]. Si–Mn steel is superior to plain carbon steel, under repeated impact, only above a certain impact value. For equal hardnesses, Si–Mn steel has lower tensile strength and yield point, but higher elongation, reduction in area, impact value, and durability.—K. E. J.

Considerations Involved in the Selection and Use of Stainless Steels. E. Smith. (*Sheet Metal Ind.*, 1953, **30,** Sept., 763–766, 820). Considerations involved in the choice of stainless steel for both domestic and industrial uses are discussed. Compositions and very brief details of the corrosion resisting properties and typical applications of most of the available types are presented.—P. M. C.

Study on Pearlitic Malleable Cast Iron. S. Maekawa. (*Tetsu to Hagane*, 1949, **35,** May, 137–141). [In Japanese]. Various experiments were made, to achieve a good pearlitic structure, and the effects of silicon content, heating and cooling conditions, and chemical composition, are reported. Free ferrite is eliminated most effectively when the manganese content is 0·7–1·25%.—K. E. J.

The Structure of Carburized Case of Si–Mn–Cr Steel Containing Mo (II). M. Yamaki. (*Tetsu to Hagane*, 1949, **35,** Sept., 302–305). [In Japanese]. The influences of cooling velocity and of each of the elements silicon, manganese, chromium, and molybdenum on the case structure were studied. The relationship with bainite was also examined.—K. E. J.

On the Residual Stress of Carburized Case of Steel. M. Yamaki. (*Tetsu to Hagane*, 1949, **35,** Dec., 431–434). [In Japanese]. In Armco iron and Si–Mn–Cr–Mo steel, the high carbon portion is under compression, and the low carbon portion under tension. The structure in the case analogous to bainite is also under compression. (11 references).

A New Building for Research Laboratory. W. Jäniche and W. Puzicha. (*Tech. Mitt.*, 1952, Oct., (7), 2–11). After a brief review of the expansion of the laboratories since the first world war, the lay-out and scope of the recently completed building at Rheinhausen is described.—R. P.

METALLOGRAPHY

Pioneer Microscopists of the Seventeenth Century. R. E. Girton. (*Proc. Indiana Academy of Science*, 1952, **62,** 281–286).

Recent Progress in the Use of the Microscope in Industrial Research. (*Echo Mines*, 1954, Jan., 51–54). Recent improvements and alterations in the design of microscopes are given. Among the subjects briefly discussed is the ultraviolet microscope which has been used to examine microstructures of steel which are not capable of being resolved by the ordinary light microscope.—B. G. B.

Metallic Grating Replica as Internal Standards for Calibrating Electron Microscopes. S. R. Rouze and J. H. L. Watson. (*J. App. Phys.*, 1953, **24**, Sept., 1106–1109). Metallic replica of diffraction gratings have been made by a direct-stripped method. Because of their superior optical properties, the spacing can be determined spectroscopically more conveniently and with greater accuracy. The electron microscopy of the metallic replicas and the accuracy and constancy of their magnification measurement are discussed.—J. O. L.

The Application of Coloured Micrographs, by the Formation of Thin Interference Films, to the Study of Aluminium, Iron, and Copper. P. Lacombe and M. Mouflard. (*Metaux-Corrosion-Indust.*, 1953, **28**, Dec., 471–488). The formation of a coloured image of a surface by interference films, the use of polarized light or the selective corrosion of certain crystal faces, is first examined. The preparation of the metal surface for examination and the technique adopted in this study are explained. Certain oxidizing reagents are known to colour steels and this forms the basis of the examination of specimens as ferrite, for example, is not coloured; the use of 'temper' films is also discussed. Twenty coloured micrographs illustrating the application of this technique are given.—B. G. B.

The Intensity Measurement of Small X-Ray Diffraction Spots by Projection of a Positive Print. Doris Evans and S. Weissmann. (*J. Opt. Soc. Amer.*, 1953, **43**, Dec., 1183–1185). The positive print method of measuring the integrated intensities of X-ray diffraction patterns has been combined with a projection and photometering apparatus. The time required for the intensity measurement of a single small spot is approx. 30 sec. The apparatus and typical results are described.

The Electronic Structure of Some Body-Centred Cubic Metals. G. G. Hall. (*Proc. Phys. Soc.*, 1953, **66A**, Dec., 1162–1171). The electronic structure of a body-centred cubic metal is considered using the standard excited state extension of the equivalent orbital method. The form of the energy surfaces for both the standard excited state and the ground state is deduced in terms of a small number of parameters using the transformation properties of a determinant wave function.— R. A. R.

Heat Treatment of Cast Iron. I. Duncan. (Inst. British Foundrymen: *Engineer Foundryman*, 1953, **18**, Dec., 69–75). An elementary account of the metallography of steels and irons and the effect of alloying elements is given. Various heat-treatments are briefly discussed.—A. D. H.

A Graphite Tube Resistance Furnace and Voltage Regulator for Equilibrium Studies in the Temperature Range 1500–1800° C. W. E. Dennis, F. D. Richardson, and J. H. Westcott. (*J. Sci. Instruments*, 1953, **30**, Dec., 453–453). The furnace described is a graphite tube resistance furnace with water-cooled contact blocks. The life of the tube was prolonged from 3 to about 45 days by packing with crushed coke, in an atmosphere of argon. A temperature of 1750° C. could be maintained at 2·5 to 3·0 kVA.—L. D. H.

Solutions in Liquid Iron. Part 2—The Influence of Sulphur on the Solubility and Activity Coefficient of Carbon. J. A. Kitchener, J. O'M. Bockris, and D. A. Spratt. (*Trans. Faraday Soc.*, 1952, **48**, 608–617). The solubility of graphite in liquid iron has been measured in the temperature range 1200–1700° C. and with the addition of 0 to 1·4% of sulphur. Sulphur reduces the solubility of graphite. The reduction is approximately to the sulphur concentration. The results for 0 to 0·84% sulphur can be represented by:

$$[C] = 1{\cdot}19 + 0{\cdot}00262\,t - [S][1{\cdot}67 - 0{\cdot}001\,(t - 1200)],$$

where [C] is the weight of carbon in 100 g. of solution containing [S] g. of sulphur, saturated at $t°$ C. It is suggested that carbon exists in liquid iron as a small positive interstitial ion and sulphur as a weakly negative substitutional ion.—R. A. R.

Solutions in Liquid Iron. Part 3—Diffusion of Cobalt and Carbon. D. W. Morgan and J. A. Kitchener. (*Trans. Faraday Soc.*, 1954, **50**, Jan., 51–60). A technique has been developed for determining the diffusion coefficients of solutes in liquid iron. Radio-tracers are used to obtain concentration-distance curves after diffusion has occurred along a narrow column of iron. The method was tested using carbon and cobalt as the diffusing elements. The results can be accounted for by treating liquid Fe–Co solutions as substitutional alloys and Fe–C solutions as disordered austenite.—R. A. R.

Anisothermal Decomposition of Austenite in a Medium Alloy Steel. P. T. Moore. (*J. Iron Steel Inst.*, 1954, **177**, July, 305–311). [This issue].

Contribution to the Knowledge of the System Tungsten-Carbide/Titanium-Carbide/Chromium-Carbide. O. Rüdiger. (*Metall*, 1953, **7**, Dec., 967–969). Experiments in which lattice constants and microhardness of the TiC–WC–Cr_3C_2 system were examined, are reported.—J. G. W.

CORROSION

Corrosion: A Field for Action. W. H. J. Vernon. (*Chem. Indust.*, 1953, Sept. 19, 982–987). The author details the research carried out on corrosion in its various aspects and emphasizes the importance of integration, *e.g.*, by the establishment of a Corrosion Research Station, in order to correlate findings and reduce the wastage arising from this cause. Education in the prevention of corrosion by the use of suitable structural materials and protective coatings, is also advocated.—J. O. L.

Corrosion. M. G. Fontana. (*Indust. Eng. Chem.*, 1953, **45**, 91A–94A). A review is given of recent work on the effects of velocity of acid flow and galvanic coupling on the corrosion of aluminium and 18/8 stainless steel by strong HNO_3. There is evidence that aluminium may provide protection for stainless steel in the fuming acid at 108° F.—K. E. J.

Radiography as an Aid in Corrosion Studies. H. A. Liebhafsky and A. E. Newkirk. (*Corrosion*, 1953, **9**, Nov., 432–435). The value of contact radiographs in corrosion studies is illustrated by results of tests on stainless steel in ferric chloride solution. The radiographs reveal differences not visible in photographs.—J. F. S.

Corrosion of Buried Copper and Ferrous Strip in Natural and Salted Soils. Section V: Earthing, Safety and Circuit Problems. (*Brit. Elect. Allied Ind. Res. Assoc., Tech. Rep.* V/T 110, 1950). An investigation to determine the relative corrodibility in different soils of copper, cast iron, mild steel, galvanized mild steel, and Armco iron is reported. In natural soils unprotected specimens lost up to nearly 2% per year; the figure was higher in salted soils. In general, mild steel is given considerable and apparently permanent protection by galvanizing.—R. A. R.

Progress Report on Development of a New Accelerated Corrosion Test. W. L. Pinner. (*Plating*, 1953, **40**, Dec., 1376–1384). The proposed programme of research to develop a new test is detailed. It will consist of field tests in Chicago, the gathering of all relevant data on factors which are known or suspected to cause deterioration of plating, and accelerated corrosion tests.—A. D. H.

Surface Reactions of Steel in Dilute $Cr^{51}O_4^{11}$ Solutions: Applications to Passivity. R. A. Powers and N. Hackerman. (*J. Electrochem. Soc.*, 1953, **100**, July, 314–319). The interactions between a steel surface and very dilute solutions of sodium chromate containing a radioactive isotope of chromium were studied by radiotracer and contact potential measurements. When the chromate solutions were sufficiently concentrated, the steel became passive and chromate ions are adsorbed. Corrosion occurred in dilute solutions. Radioactive chromium in excess of that associated with a passive surface appears on both anodic and cathodic areas.—A. D. H.

Corrosion of Steel by Air-Free, Dilute, Weak Acids. N. Hackerman and E. E. Glenn, jun. (*J. Electrochem. Soc.*, 1953, **100**, Aug., 339–344). The corrosion of mild steel in solutions containing up to 1000 p.p.m. acetic acid and 1000 p.p.m. NaCl, through which CO_2 was bubbled in the absence of air, was studied. With less than 500 p.p.m. of acetic acid the corrosion rate was inversely proportional to the acid concentration. Using 500–1000 p.p.m. acetic acid the corrosion rate was low. The corrosion rate was independent of the CO_2 partial pressure up to 1·5 atm. CO_2 when a substantial increase was observed. It is postulated that fine particles of corrosion product are formed at the higher acid concentrations, whereas the coarser particles formed at low concentrations yield a porous film which is non-protective.—A. D. H.

Study of the Oxidation of High Purity Iron and of the Modes of Decomposition of Ferrous Oxide. R. Collongues, R. Sifferlen, and G. Chaudron. (*Rev. Mét.*, 1953, **50**, Oct., 727–736). The importance of various factors in the oxidation of very high purity iron and the effect of traces of impurities on the structure of the ferrous oxide film were investigated and the conditions of thermal treatment affecting the decomposition of ferrous oxide were also determined.—A. G.

An Investigation of Accelerated Oxidation of Heat-Resistant Metals Due to Vanadium. F. C. Monkman, and N. J. Grant. (*Corrosion*, 1953, **9**, Dec., 460–466). The effects of refractory

metal oxide additions to vanadium oil ash on the physical properties and corrosion by the ash are described. Magnesium, calcium, and nickel oxides increase the melting point of the ash and reduce the accelerated corrosion of stainless steel by it. Sodium sulphate promotes accelerated attack by lowering the melting point of V_2O_5 but at higher temperatures it inhibits attack. Chemical analysis and X-ray diffraction studies of the oxide scale formed by accelerated corrosion of a stainless steel in liquid V_2O_5 show that the oxygen and vanadium concentrations are greatest at the metal–oxide interface. Evidence of a metal/vanadium-oxide compound has been found near the metal–oxide interface. This compound in equilibrium with liquid V_2O_5 on the metal is said to cause the accelerated oxidation.—J. F. S.

Cathodic Protection and High Resistivity Soil. H. C. van Nouhuys. (*Corrosion*, 1953, **9**, Dec., 448–459). Since January 1941, 320 miles of 8-in. bare pipe have been protected by means of 25 rectifiers. The system lowers the pipe-to-soil potential a minimum of 0·3V. based on a remote electrode. The soil resistivity often exceeds 100,000 ohm/cm. Details of the installations are given; the method of protection is justified. A comparative trial, on a 6-in. pipe, between magnesium ribbon anodes, ordinary magnesium anodes, and a rectifier system, showed the rectifiers to be the most economical.

Corrosion by Aqueous Solutions at Elevated Temperatures and Pressures. F. H. Beck and M. G. Fontana. (*Corrosion*, 1953, **9**, Aug., 287–293). Extensive data on the corrosion of stainless steels, cast titanium, and high-silicon iron at elevated temperatures and pressures have been obtained in laboratory autoclaves. In nitric, phosphoric, and acetic acids, and NaOH solutions corrosion rates usually increase rapidly above boiling. Inhibition by copper ions in phosphoric acid can be very effective. Sub-surface corrosion of stainless steel by hot caustic soda is described.—J. F. S.

Corrosion of Steel in Dilute Solutions of Sodium Salts of Weak Acids. M. J. Pryor. (*Corrosion*, 1953, **9**, Dec., 467–477). Steel immersed in dilute solution of sodium carbonate, sodium silicate, disodium phosphate, or trisodium phosphate, with or without chloride ions, suffered either general attack, local attack or, in carbonate–chloride solutions, pitting. It is suggested that, if the corrosion product is of high permeability and low resistance, uniform attack takes place under cathodic control. If it is more impermeable and of higher resistance, the rate of attack is greatly reduced and corrosion is under anodic control. Chloride ions migrate and diffuse readily and so lower the internal resistance of the corrosion cells. The structure of the rust blisters and the constitution of the rusts are examined.—J. F. S.

Accelerating Effect of Decreasing Temperature on Corrosion by Glycol Solutions. D. Caplan and M. Cohen. (*Corrosion*, 1953, **9**, Aug., 284–286). The corrosion of galvanized steel in ethylene glycol solutions containing borax increases with decreasing temperature. At 75° F. and below, borax accelerates the corrosion of zinc, cadmium, magnesium, and brass in 50% glycol owing to the formation of soluble complex salts instead of the insoluble corrosion products which otherwise would stifle the attack. Zinc is also attacked in glycol solutions containing sodium acetate or benzoate.—J. F. S.

Filiform Corrosion. M. van Loo, D. D. Laiderman, and R. R. Bruhn. (*Corrosion*, 1953, **9**, Aug., 277–283). Filiform corrosion occurs in humid conditions on steel and other metals. It begins randomly but grows uniformly under both non-metallic and metallic coatings if these are semi-permeable and sufficiently elastic to yield without rupture. It is not related to the metallurgical pattern on the surface, or to illumination, biological activity, or the presence of inhibitive pigments. On steel, it is suggested that the active head contains ferrous corrosion products and the track ferric salts. An electrolytic mechanism is proposed by which adjacent anodes initiating the head and an oxygen concentration cell supplying the driving force. The straightness of the tracks is due to precipitation of insoluble corrosion products on the sides of the head.

Corrosion Resistance of High-Strength Low-Alloy Steels as Influenced by Composition and Environment. C. P. Larrabee. (*Corrosion*, 1953, **9**, Aug., 259–271). Although high-tensile steels are often several times more resistant to corrosion than mild steel, the conditions of exposure have an important effect on actual and relative corrosion rates. The nature of the rust film largely governs the rate of attack. Under immersion conditions only chromium is likely to improve the corrosion resistance of structural steels. In soil the effects of alloying elements on corrosion rates are small compared with the variations due to different soil conditions. Results of exposure tests on structural steels are presented. (41 references).—J. F. S.

Cathodic Protection of Active Ships in Sea Water with Graphite Anodes. K. N. Barnard, G. L. Christie, and J. H. Greenblatt. (*Corrosion*, 1953, **9**, Aug., 246–250). Trials on the cathodic protection of three steel tugs using an impressed current and graphite anodes are described. Satisfactory operation can be obtained by shielding the hull round the anodes with vulcanized rubber. Flame sprayed polymers are also promising but not paint films.—J. F. S.

The Protection of Mild Steel by Films of Lanolin. L. Whitby. (*Chem. Indust.*, 1953, Sept. 12, 974). The poor protection afforded by lanolin films less than 2μ thick is related to the presence of air-borne particles of greater size capable of penetrating the film and providing access for moisture. Indirect confirmation is provided by the lack of corrosion evident in salt-spray tests on similar coatings.

On the Corrosion-Resisting Properties of Special Steel. S. Koshiba and K. Harada. (*Tetsu to Hagane*, 1949, **35**, Dec., 425–430). [In Japanese]. Results of tests with various acids and salts are reported. Cr–Ni alloy steels showed high corrosion resistance. That of low-carbon steels was reasonable in acids except HNO_3, while that of high-carbon steels was poor.—K. E. J.

Corrosion Tests for Liquid Metals, Fused Salts at High Temperatures. D. C. Vreeland, E. E. Hoffman, and W. D. Manly. (*Nucleonics*, 1953, **11**, Nov., 36–39). Techniques are described for the static and dynamic testing of corrosion in liquid metals and fused salts. In static testing, the specimen is loaded into a tube of the same material, together with the corroding medium in a dry box in a helium atmosphere sealed with vacuum tape and evacuated. Methods of dynamic testing used at Oak Ridge are described; they consist of a see-saw furnace test, a spinner test for investigating high velocity corrosion, a thermal convection loop, and a 'whirligig' oscillating test.—L. D. H.

Investigation into the Corroding Effect of Ammonium Salts on Metals. H. Stäger. (*Eidgenössische Technische Hochschule in Zürich, Thesis No.* 2157, 1952). After discussing theoretical principles, the author describes conditions and apparatus used to investigate the corroding effect of some ammonium salts on cast iron, steels, and brass. The relation between the method of testing and the corrosion is dealt with. Tests are described to establish the influence of oxygen, temperature, concentration, *p*H, and the addition of small amounts of other substances to the corroding solution.—R. P.

Boiler Feed Water Treatment for Advanced Steaming Conditions. J. Leicester. (*Overseas Eng.*, 1954, **27**, Jan., 206–211). Recommendations are made for conditioning feed water for boilers operating at high temperature and pressure. One proved method of reducing the danger of local film concentration and deposition of solid matter is to substitute potassium for sodium in feed-water chemicals.—R. A. R.

Electrical Treatment of Boiler Feed Waters. H. F. Hurley, H. Ingleson, W. J. Sparkes, and R. Wilkinson. (*Corrosion*, 1953, **9**, Aug., 251–258). Devices using small electric currents to induce sludge to form instead of scale are cheap to use. Two series of tests of the efficacy of such methods are described. The observed wide differences in the deposits formed in the experiments had no significant connection with the electrical treatments of the feed waters.—J. F. S.

ANALYSIS

Spectrography in the Iron and Steel Industry. J. Humbert. (*Bull. Cercle Etudes Mét.*, 1953, **6**, June, 149–162). A review of the principles of spectroscopic analysis is made first and is followed by a short description of spectrometers. Examples of the use of the spectroscopic method for the analysis of a number of elements are given. Methods used to estimate the percentage of an element from the intensity of the lines on a photograph are explained.—B. G. B.

A New Approach to Direct Reading Spectrochemical Analysis. R. K. Brehm and V. A. Fassell. (*J. Opt. Soc. Amer.*, 1953, **43**, Oct., 886–889). In this new direct-reading instrument for spectrochemical analysis a single multipler phototube is used in combination with a rapid-scanning spectrometer. As the spectral lines cross the single exit slit, voltage pulses are generated by the phototube and are panoramically presented

on an oscilloscope whose time-base is synchronized with the ing them to "bursts" of constant-amplitude pulses whose spectrum scan. The pulse heights are measured by convert-number is proportional to the magnitude of the original spectral line pulse. The pulse bursts corresponding to the lines whose intensity is of interest are separated by means of electronic gates. High-speed scalers and mechanical registers indicate the time integrals of the spectral line intensities. Intensity ratios are automatically computed after the exposure and recorded on a chart.—J. O. L.

A High-Speed Cathode-Ray Indicating Spectrophotometer. R. C. Beitz. (*J. Opt. Soc. Amer.*, 1953, **43,** Sept., 773–779). A new instrument for displaying spectrophotometric curves almost instantly on a cathode-ray tube is described. The curves are presented on a linear percentage transmission scale and a linear wavelength scale. A novel sweep circuit, not an oscillator, is utilized to cause the cathode-ray tube spot to move non-linearly with respect to time so as to compensate for the non-linear dispersion of the optical system and plot the spectra on a linear wavelength scale.—J. O. L.

Precision X-Ray Diffraction Spectrometer Ring. D. C. Barnes and C. Wainwright. (*Engineer*, 1954, **197,** Jan. 15, 97–98 ; *Engineering*, 1954, **177,** Jan. 15, 82–83). The authors describe the design and construction of a precision X-ray diffraction spectrometer ring at the National Physical Laboratory to improve and further the knowledge of Geiger-Muller counter techniques. The instrument consists of a stator and a rotor both having a central circular aperture 14 in. in dia. and capable of accuracies of rotation of $\pm$ 20 seconds of arc. Provision is made for kinematically supporting specimen holders and enclosures within the central aperture of the spectrometer ring.—M. D. J. B.

The Suitability of Photographic Material for Use in Raman Spectrography. H. Houtgraaf. (*Chem. Weekblad*, 1953, **49,** Dec. 26, 973–979). [In Dutch]. A survey is made of factors determining the quality of photographic materials and 36 different kinds of plates are compared.—R. A. R.

Different Methods for the Spectrographic Analysis of Steels. Jean. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 15–29). Three classical methods for the quantitative evaluation of spectrograms are reviewed. Recent work by English authors is shown to be essentially an internal standards method. A simple and rapid method is evolved for the calculation of results.—R. P.

Some Experimental Difficulties Encountered in the Direct Evaluation of Spectral Intensity Lines. W. Van Tongeren. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 33–40). The following reasons for the disagreement of results are given : (1) Loss of electricity due to leakage in the resistances ; (2) loss because of parasitic capacitors ; (3) influence of prevailing temperature and pressure ; (4) properties of photo-electric cells ; (5) and interferences with the measuring circuit caused by the high-frequency emitted from the source. Supporting experiments are described. It is recommended that the source should be more efficiently stabilized, both optically and from an electric point of view.

Charcoal Used in Spectrography. Parisot. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June 1950, 41–42). The ash content of carbon electrodes is rarely below 0·1%. The author claims to have produced graphite, with an ash content less than 0·01% and this is now commercially available in the form of electrodes. Work is in progress to obtain even purer carbon.—R. P.

Developing a Method for the Spectrographic Determination of Carbon in Steels. G. Brucelle. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques. 13th Congress*, June, 1950, 43–47). Of the few wavelengths available for the determination of carbon, the line 2296·86 is considered the most suitable although the photographic emulsion is not very sensitive to that wavelength ; high excitation potentials are involved. The interference of the Fe 2296·92 line is negligible for C $>$0·2%. Tests are described to obtain the best conditions, and conditions are recommended for use with the Zeiss QU24 spectrograph.—R. P.

An Electronic Multispectrometer: Application to the Determination of Carbon in Steel. R. Breckpot and M. de Clippeleir. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 51–59). An electronic mass-spectrometer is described, the instrumental error being less than 1%. Four elements can be determined simultanously. The determination of carbon is discussed briefly.—R. P.

A Direct-Reading Spectrograph. J. Orsag. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques. 13th Congress*, June, 1950, 61–73). A direct-reading attachment is described which can be used with any spectrograph. The range is 2300Å–6000Å, using special glass windows, or 1800Å–6000Å if quartz is employed. R. P.

High Luminosity Spectrographs. J. Cojan. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 81–87). Optical considerations for the visible regions of the spectrum are expounded. Two optical systems are explained by means of diagrams. The compound prism used is claimed to be at least as efficient as a grating.—R. P.

Spectrophotometry of Rapid Combustion High Temperature Flames. Libessart. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 103–130). An apparatus and technique are described for measuring high temperatures which change rapidly. A reference standard is used for the measurement of spectral intensity. Differential methods (in particular the two-colour technique) are not favoured by the author. The method is applicable to research into changes occurring during melting, refractory materials, and to high velocity reactions at any wavelength.—R. P.

A New Lamp and New Raman Spectrograph. A. C. Menzies. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 131–145). A source for Raman spectroscopy is described, based on a new principle. The spectrograph uses two cameras. Results using 6 c.c. liquid are given, using (*a*) a photographic method and 1 min. exposure, and (*b*) using a photo-multiplier followed by direct reading.—R. P.

A Contribution to the Comparative Study of the Feussner and the Multisource Generators, with Reference to the Analysis of Iron and Steel. P. Michel. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 147–155). A comparison between the two instruments is made, particularly as regards the luminosity and reproducibility of the discharge. Only a few steels have been used for this work and it is suggested that further tests be carried out, using samples of varying metallurgical history.—R. P.

Research on a Sensitive Photographic Emulsion for Rapid Spectrographic Analysis. P. Michel. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 157–161). The characteristics of emulsions E.S.A.1 and 1357 are compared as to their sensitivity, speed, wavelength sensitivity, grain size, and constancy. A table of comparison is given.

Studies of the Spectra Obtained from Pure Iron and from Iron Sulphide. H. Triché. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 13th Congress*, June, 1950, 167–174). A Tesla spark discharge is used and the excitation conditions are given. The spectra emitted by pure iron and by iron sulphide are compared.—R. P.

Electro-Multiplier Cells and Mountings Used in Direct Analysis. Macq. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques. 14th Congress*, June, 1951, 25–61). This paper deals with the stages involved when light energy is converted into electrical energy. Descriptions are given of the electronic system, the slit, optical parts, electron multiplier cells, and an electronic device for the measurement of the energy of the spectrum lines under consideration.—R. P.

Spectrographic Determination of Minor Constituents in Steels. G. Brucelle. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 14th Congress*, June, 1951, 63–79). Conditions for the determination of the following elements are given : Mo up to 0·02% ; Si up to 0·02% ; V up to 0·06%. The arc technique is more sensitive than the sparking method. For these low amounts it is recommended that lines of neutral atoms are used which correspond with recognized emission methods.

Spectrographic Analysis of Metallic Surface Layers. Application to the Layers Obtained by Thermal Diffusion of Chromium in Iron and Steel. F. Malamand. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 14th Congress*, June, 1951, 85–113). A method is described for the spectrographic determination of 10–50% Cr in binary Fe–Cr alloys. This method can be applied also to the determination of chromium in layers after diffusion. Experimental values agree well with those expected theoretically. A spark discharge is used and the necessary conditions stated. The diffusion of carbon is also studied. (19 references).—R. P.

Spectrographic Calculations by Means of Straight-line Graphs. W. Pasveer. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 14th Congress*, June, 1951, 117–153). A new graphical method is suggested for the evaluation of spectrographic results ; it is chiefly a nomographic calculation. The method is based on theoretical considerations and not on experimental results. The author considers that further work ought to be carried out.—R. P.

Chemical Examination of Rust by the Internal Differential Method. J. Verbestel, A. Berger, and J. Pirotte. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 14th Congress*, June, 1951, 221–224). The authors advocate the use of the ratio of two elements present in order to avoid weighing on the microbalance, the spectrograph being considered well suited to this ratio method. The specimen can be mounted in resin provided the latter does not contain any of the elements to be determined.—R. P.

A New Spectrograph for Qualitative and Quantitative Analysis. J. Cojan. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 14th Congress*, June, 1951, 225–233). This spectrograph is more robust and takes up less space than conventional models. The instrument covers the spectral range 2150–5893Å and is particularly suitable for non-ferrous work. Steels with high tungsten, chromium, and molybdenum contents require greater dispersion. The lens system is achromatic.—R. P.

The Zirconium Arc Lamp. Beaudouin. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 14th Congress*, June, 1951, 235–243). The construction of a zirconium arc lamp and its operation are described. The emission is rich in infra-red radiations, reliable and very intense, it is operated in an inert gas atmosphere and the light can be modulated like that emitted by a carbon-arc lamp.—R. P.

Spectroscopy and Radio-Spectroscopy. R. Freymann. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 17–25). An outline is given of the application of Hertz's spectroscopy to the study of molecules and atoms. The reversion and rotation bands of molecules in the vapour state are considered, together with their application to analysis and to the study of isotopes. Molecules in solids and the various types of resonance in atoms are discussed.

Spectrophotometry. Jean. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 27–28). A short summary is given of the principles involved in colorimetric analysis and some likely errors.—R. P.

Construction of a Spectronograph Using an Image Converter. E. Funfer. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrotgraphique des Produits Métallurgiques, 15th Congress*, June, 1952, 29–39). This instrument is fully described. The spectrum is reproduced at the photo-cathode of an image converter where it is deflected by a magnetic field. This deflected spectrum is reproduced in the slit of a multiplier. The spectrum is projected on to the screen of an oscillograph by synchronizing the deflection of the electronic image in the transformer.—R. P.

Influence of the Physico-Chemical State on the Spectral Emission of a Mottled Pig Iron. J. M. Lopez de Azcona and E. A. Alvarez-Arenas. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 41–45). Tests and graphs are described which show that microstructure influences spectral emission and that results vary with the form in which carbon is present.—R. P.

Recent Improvements of Sources for the Purpose of New Applications. R. C. Durr. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 47–55). Improvements in the universal source for the purpose of direct reading and the determination of very low amounts are discussed.—R. P.

A Rapid Photographic Method for the Measurement of Flame Temperature Based on the Reversal of Spectral Lines. G. H. Young and P. A. Tyler. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 83–95). This apparatus consists mainly of a constant deviation spectrometer, two photographic oscillographs and a rotary disc, the latter governing the exposure time. Temperatures between 1500 and 2500° K. can be measured to within ±20°, between 2500 and 3800° K. to within ±30°. Some disadvantages and their remedies are discussed.—R. P.

Optical Emission Spectra in the Transformation of the Fe-C System (Steels). A. Camunas. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 161–167). Emission spectra are shown to depend on the structure of steels if ΔS is determined or the blackening by the line pair Fe 2298·23 C 2296·8. The use of quenched electrodes is recommended. The decomposition of martensite is studied spectrographically.

Characteristics of a Water-Cooled Lamp with Concave Cathode. J. Roig and M. Bécart. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 169–181). The principles and construction of a concave cathode lamp and its performance using air, helium, and argon are discussed. Pressures of about 0·1 mm. Hg are used and the lamp is water-cooled. Characteristics depend on degasification by the cathode.—R. P.

Rapid Photometric Analysis of Steels. Piper and Hagedorn. (*Groupement pour l'Avancement des Méthodes d'Anaylse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 185–199). A photo-electric double beam colorimeter is described, using colour filters. Methods for the determination of molybdenum, nickel, cobalt, copper, tin, and tungsten are briefly stated.—R. P.

A Spectrograph for the Near Infra-Red. Beaudouin. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques, 15th Congress*, June, 1952, 235–253). The apparatus consists of a Nernst source, optical bench, the spectrograph itself, amplifier, and a three-speed registering device. Optical mounting is of the Pfund type. This spectrograph is particularly suitable for the study of structures of liquids and solids.—R. P.

Spectrographic Technique and Its Part in the Foundry. W. J. Price. (*Groupement pour l'Avancement des Méthodes d'Analyse Spectrographique des Produits Métallurgiques. 15th Congress*, June, 1952, 263–281). Spectrographic analyses of pig iron, white and grey iron, alloy cast iron and slags are discussed, including the determination of minor constituents and traces of calcium, magnesium, and zinc.—R. P.

Second International Colloquium on Spectrochemistry. (*Spectrochimica Acta*, 1952, **5**, June, Special Issue, 1–200). This Colloquium, organized by the Centro di Richerche Spettrochimiche Associazione Italiana di Metallurgica, was held in Venice on September 14–16, 1951. Abstracts of papers of interest to the iron and steel industry follow :

Some Improvements in Apparatus for Spectrographic Analysis. H. Bückert. (5–8). [In German]. Medium dispersion spectrographs, still employed in many European laboratories for metallurgical analysis, can be extended in usefulness by adopting modern accessories such as the high-capacity controlled spark generator, the heavy-current time-controlled interrupted arc and the high-sensitivity double-beam comparator. Improved dispersion can also be obtained with a curved-surface prism and rapid measurement with a direct-reading photocell assembly.—J. O. L.

A New Simplified Direct-Reading Attachment. J. Orsag. (9–10). [In French]. The plate-holder of a two-prism spectrograph of aperture f/14, giving a spectrum 103 mm. long from 2145 to 6000Å and equipped with controlled-spark discharge unit, can be replaced by a direct-reading assembly containing two photo-multiplier cells and equipped with a series of fixed slits and mirrors for selection of appropriate lines. Photographic reproducibility is enhanced by a special densitometer.—J. O. L.

The Influence of Free Energy and Character of the Discharge on the Emission of Spectral Lines. G. Brucelle. (11–17). [In French]. Increased energy in the discharge corresponds to the emission of ionized lines of greater excitation potential. This can be achieved by an increase in the capacity and voltage or in the current by means of the Durr combined France/GAMS generator, facilitating the analysis of trace impurities (0·01%) in steel from arc or spark-like discharges.—J. O. L.

Spectrographic and Electrical Characteristics of Low-Pressure Sparks. J. van Calker. (19–23). [In German]. With an auxiliary electrode to trigger the spark, it has been possible to obtain a spark at 220 V. D.C. with a capacity value up to 2000 μFarad and an inductance of no more than 0·03 mH. in the discharge circuit and intensities of up 10,000 amp. Current intensity, ignition voltage, and sparking time length have been determined by the oscillograph. The corresponding spectra of the iron electrodes which have been used show a systematic variation of the spectral character of the discharge with energy and time. With the delay at the beginning of the discharge at very high energy levels important deviations from the running of a free discharge can be observed. By decreasing the electrode diameter, the spectral characteristics can vary, from a spark-like to an arc-like type.—J. O. L.

The Suitability of Grating and Prism Instruments for Spectrographic Work. A. Gatterer. (30–35). [In German]. The first part of the report discusses the optical and mechanical requirements for efficient operation of a spectrograph, the second and third parts assess the suitability of grating and prism spectrographs in meeting these requirements. The former are preferred for quantitative analysis, and a versatile large grating spectrograph is described.—J. O. L.

Some Aspects of Quantometric Calibration. A. Giavino. (52–62). [In Italian]. The principles of spectrochemical calibration are outlined and the analogy of photographic and quantometric calibration methods is discussed. After describing the usual calibration method using two standard samples, the author describes two other methods ; one of these uses a standard lamp, and analytical results obtained in this way are tabulated. The other proposed method would use a step wedge, but it has not been tried.—J. O. L.

Spectrographic Determinations of Silicon in Cast Iron and Observations of the Corresponding Microstructure. M. S. Rosetta. (77–86). [In Italian]. Spectrochemical determinations of silicon in cast iron using a spark source and quartz spectrograph of medium dispersion are discussed, and a comparison made of the effect on spectrochemical results of the diameter of the cast electrodes. This is partially explained by variations in the microstructure of the cast bars ; and a pearlitic structure is to be preferred.

The Spectrographic Analysis of Foundry Iron. R. Berta and A. Palisca. (87–96). [In Italian]. In routine spectrochemical analysis of cast iron for foundry control a spark source and spectrograph of medium dispersion were used. Difficulties in obtaining accurate results for silicon were eliminated by improving the method of casting and preparing the samples ; the best results were obtained with two cast pencils of the sample and not with a disc and counter-electrode. The standard deviation of the precision of replicate analyses is below 2% for Si and Mn, about 5% for Cu, Mo, and other elements. The mean differences between chemical and spectrographic analysis are also discussed.—J. O. L.

The Influence of Direct Reading (Quantometric) Spectrographic Analysis in the Production Control of Special Steels. L. Benussi and A. Caroli. (97–113). [In Italian]. The importance of choice of lines and channels, and of grouping steel types for foundry control by the quantometer is discussed, with detailed examples of sources of error. Tables are given for arbitrary correction factors based on comparative experience of spectral and chemical analysis.

A New Recording Microphotometer for Spectrometry. P. Mathiot. (124–129). [In French]. A recording microphotometer is described with an electronic amplifier and a moving wedge, automatically operated to balance the measured beam. A lever which follows the movement of the wedge carriage ends in a ball pen, and records the density of the area scanned with a variable magnification (between X2,5 and X100) of the traverse. The precision is said to be about 0·01 density units between 0 and 4. The instrument is operated from the mains, and needs only 5 min. to warm up.—J. O. L.

Collaborative Spectrographic Analysis of Low Alloy Steels. C. Rossi and R. Intonti. (147–157). [In Italian]. Summarizing some of the results of a collaborative comparison of spectrographic data for the analysis of low-alloy steels by 18 laboratories, the advantages of this type of work are described. The principal causes of error are discussed, with particular reference to the photographic conditions. The samples compared were found to be of satisfactory homogeneity, and the method of sparking flat discs with a counter-electrode of aluminium was approved. Calibration with a step-wedge and very contrasty development is also recommended. Standard deviation within laboratories of the order of 3% for Mn and Cr, and 5% for Ni and Si were obtained.—J. O. L.

Quantitative Spectrographic Analysis with the Hilger E492. G. Zanini. (158–162). [In Italian]. The use of the Hilger E492 for the routine analysis of steel is described.

Nomographic Spectrographic Calculation. W. Pasveer. (163–169). [In French]. It is possible to substitute nomographs for the curves used in spectrographic calculation, preferably after rectifying the emulsion calibration curve by a Seidel transformation. In the author's micro-densitometer a galvanometer scale with direct readings in Seidel densities has been fitted. Instructions are given for making a complete nomograph which replaces the graphical calculations usually made in the laboratory with curved calibration lines.—J. O. L.

The Automatic Direct-Reader as a Research Instrument. F. C. Mathieu. (174–181). [In French]. The use of the Radio-Cinéma instrument for routine and research work is described, including several refinements for the latter purpose.—J. O. L.

Collaborative Preparation of an Agreed Method for the Quantitative Spectrographic Analysis of Cast Iron. A. Portalupi. (182–183). [In Italian]. This paper outlines the scope of a co-operative research by five laboratories on the quantitative spectrographic analysis of cast iron, using spark spectra.—J. O. L.

The Principal Causes of Error in Quantative Determinations with the A.R.L. Quantometer (S.Q.A.) L. Bartoli and C. Becchio. (184–200). [In Italian]. A complete analysis of measurements made in the early stage of using an A.R.L. quantometer adapter for steel analysis is described in terms of the standard deviation of the error from various sources. The contributions made to the error by the recording channels, source, method of calibration, and degree of homogeneity of the samples are separately discussed. Finally, mean standard deviations are reported for silicon, manganese, chromium, nickel, and copper in steel. Graphical comparison of the quantometric and chemical analyses obtained in routine work is also made.—J.O. L.

Rapid Analysis of Manganese in Ferro-Manganese by Utilization of $HClO_4$. S. Maekawa and Y. Kikuchi. (*Tetsu to Hagane*, 1949, **35,** July, 215–219). [In Japanese]. A rapid method of estimating manganese in iron and steel depends on the rapid oxidation by $HClO_4$ and titration by a $KMnO_4$ method. Accurate results are obtained within 18 min.—K. E. J.

Determination of Available Sulphur in Pyrites and Pyritic Concentrates from Coal. A. R. Panicker and N. G. Banerjee. (*J. Sci. Indust. Res.*, 1953, **12B,** Sept., 417–419). A rapid combustion method has been developed for the determination of available sulphur in pyrites and coal concentrates, using a packing of quartz in the combustion furnace and a second furnace packed with carbon at 330° C. to ensure evolution of the gas as sulphur dioxide.—J. O. L.

Metals in Phosphating Solutions—Determination by Ion Exchange. G. Gabrielson. (*Metal Finishing*, 1953, **51,** Nov., 63–69). A rapid method for determining the equivalent metal content of a phosphating bath is given. The solution is passed through a cationic exchange resin column and the phosphoric acid content is determined by titration. If the free phosphoric acid content is known the metal content can be found by difference.—A. D. H.

The Analysis of Electroplating Solutions for Major Constituents. E. J. Serfass. (*Plating*, 1953, **40,** Dec., 1385–1390). The author reviews available methods for the determination

of major constituents in nickel and copper plating baths that have been studied by a committee of the American Electroplating Society. Brief recommendations are made on the accuracy, ease, and speed of certain methods. Details are given of specially developed methods for the determination of alkali-hydroxide in cyanide copper baths, and of boric acid in Watt's nickel baths.—A. D. H.

ECONOMICS AND STATISTICS

The European Steel Market 1953. (*United Nations Economic and Social Council*, E/ECE/183, E/ECE/STEEL/79, Jan. 19, 1954).

Quarterly Bulletin of Steel Statistics for Europe. (*United Nations Economic Commission for Europe, No.* 13, Dec., 1953).

Competition between Steel and Aluminium. (*United Nations Economic and Social Council*, E/ECE/184, E/ECE/STEEL/81, Feb. 12, 1954). This 152-page study defines the area of competition between steel and aluminium and considers how far aluminium is likely to become more competitive with steel and cast iron. Part I discusses in detail the growth of the aluminium industry, and Part II deals with the areas of consumption, prices and costs, and competition in several major industries.—R. A. B.

Coke and By-Products in 1952. (*Iron Steel Eng.*, 1953, **30,** Dec., 77–83). Statistical information is given relating to coke production in the U.S.A. in 1952, the number and capacity of coke-ovens, coal charged into coke-ovens, coke produced and sold or used by the producers, stocks, and values.

MISCELLANEOUS

Concepts of Dust Technology. I—Characteristic Curve, Equation, and Fraction. II—Mean Grain Size. E. Feifel. (*Radex Rundschau*, 1952, Nov., (6), 235–254 ; 1953, July, (6), 8–26). A few characteristic particle size curves of dusts are presented in the conventional manner, and the advantages and drawbacks of graphs with different scales for the abscissæ and ordinates are discussed in this mathematical paper. Methods of statistical assessment are considered and the applicability of determinations of mean sizes to dedusting techniques is examined. A technically acceptable definition of mean size is suggested and examples are quoted.

Modern Lighting Systems for Steel Mills. R. F. Vandenboom and D. L. Beeman. (*Iron Steel Eng.*, 1953, **30,** Oct., 79–87). The authors put forward standards of lighting and show how these can be achieved. Maintenance problems are discussed, as well as power distribution and methods of switching and protecting higher voltage lighting circuits. Problems of voltage flicker and reliability are also discussed.

Equipping a Modern Laboratory with an Air-conditioning Plant. E. Piper and H. Hagedorn. (*Stahl u. Eisen*, 1953, **73,** Dec. 17, 1720–1727). The design of the new laboratories at the Röchling works, Völklingen, and the air-conditioning plant installed therein are described. Even in the severe and adverse conditions of chemical laboratories, working 24 hr./day, it has been possible to maintain every room at a desired temperature and humidity.—J. P.

BOOK NOTICES

Baker, H. Dean, E. A. Ryder, and N. H. Baker. "*Temperature Measurement in Engineering.*" Volume I. 8vo, pp. vii + 179. Illustrated. New York, 1953 : John Wiley and Sons, Inc. ; London : Chapman and Hall, Ltd. (Price 30*s*.)

This book, the first of two volumes, has taken a step towards making temperature measurement a technology in its own right. It breaks with the usual tradition of expounding the physical principles and leaving the practical difficulties no more than mentioned. In this volume the authors describe, in a clear terse style, the technique of measuring the internal temperatures of solid bodies by the use of thermocouples, in sufficient detail to help the plant technician, and yet with a sufficient generality to interest all those faced with the problem of measuring temperatures.

The first four chapters are introductory to both volumes, and describe briefly the fundamental scale of temperature, the methods available for measuring temperature, the numerical treatment of errors and the way in which the particular circumstances modify the technique. The chapter on errors discusses clearly how many readings are required to achieve a given accuracy under controlled conditions, but there should have been reference to the statistical methods which enable an estimate of the error to be made in those industrial applications where the value of the temperature varies owing to the uncontrollable factors of the process.

Chapter 5 lists the thermocouple wires available, indicates tests for inhomogeneity and describes how the hot junction may be soldered, brazed or welded. This is followed by a short chapter on indicating instruments, which, acting as a convenient collecting point for references to recent American practice and commercial instruments, needs supplementing for British readers.

Chapter 7 presents graphical solutions of the error due to the disturbance of the thermal equilibrium by the heat transferred from the point of measurement to the surroundings by the thermocouple leads and their insulation. There is an excellent chapter on the technique of drilling deep holes and a useful account of the properties of special materials, heat-resistant metals, plastics, refractories and cements. The remaining three chapters describe in detail, particularly with reference to the internal-combustion engine industry, methods of installing thermocouples in solids using peened and pierced-in junctions, welded junctions, soldered and cemented junctions, and plugs with junctions. Throughout these chapters, the text is liberally illustrated with well-drawn diagrams.

The layout of the book is attractive, and it is generously stocked with recent references. It is worth purchasing, and it will be interesting to see if this high standard is maintained in the second volume.—E. J. Burton

Deutsche Gesellschaft für Chemisches Apparatewesen E.V. "*Dechema-Werkstoff-Tabelle.*" Chemische Beständigkeit der Werkstoffe. 3. Bearbeitung. Folio, loose-leaf. Parts 1 and 2, approx. 100 sheets (200 pp.) each. Weinheim-Bergstrasse [1954] : Verlag Chemie G.m.b.H.

This compilation is in loose-leaf form, each sheet dealing with the effect of one chemical substance upon a range of materials, of which 57 are the common metals and alloys, 14 are materials of chemical construction such as glass, enamel, porcelain, etc., and 25 are other materials used in chemical engineering, such as wood-wool, natural or synthetic rubber, plastics and silicones. A code of symbols indicates, in a rough quantitative fashion, the degree of resistance to the substance, and in some cases, the temperature and pressure ; there are also explanatory notes. The substances are arranged alphabetically under their German names, of which English and French equivalents are given below. Of the volumes received, No. I goes from *Abietinsaüre* to *Ammoniumsulfit*, and No. II from *Äthylenharnstoff* (ethylene urea) to *Benzilsaüre* (benzilic acid) ; other volumes will follow.

This work is clearly of more direct value to the chemical manufacturer and engineer concerned with the preparation of a particular chemical substance, than to the metallurgist who wishes to know the resistance of his metal or alloy to a range of substances, but for many purposes it will be equally valuable to both.—J. P. S.

Georg Fischer Aktiengesellschaft. "*Aus der Entwicklung der Räder für Lastwagen and Omnibusse.*" La 8vo, pp. xii + 176. Illustrated. Schaffhausen, 1952 : Georg Fischer Aktiengesellschaft.

Of all the devices developed by man to lighten his labours first place should surely be allotted to the wheel. Any good book on the history of the development of the wheel is therefore likely to arouse the interest of both engineer and layman, and when such a book is produced by Georg Fischer A.G. of Schaffhausen to commemorate both the founding of their works 150 years ago, and 50 years of making cast-steel spoked wheels, the reader will expect something better than the average publication—and he will not be disppointed.

The chief interest of the book lies in its illustrations, of which there are over 230. These enable the reader to follow the development of the wheel from the chariots of ancient Persia (3500 B.C.) with wheels of wood right up to the motor-car and lorry wheels of the present day when

cast and rolled steel are the recognized materials in wheel construction. In the very early history it is of interest to note that the wheel preceded the roller by about 2500 years and that the disc wheel is much older than the spoked wheel.

The introduction and development of the solid, followed by the pneumatic, rubber tyre is dealt with in great detail as Georg Fischer A.G. themselves played an important part in the design and manufacture of rims suitable for these tyres.

There are descriptions and illustrations of the interior of the works of Georg Fischer A.G. showing their electric arc furnace, steel foundry, forging plant, and machine shops as they appear today. The latter half of the book consists for the most part of about 100 photographs showing enumerable types of vehicles to which their wheels have been fitted. A classified bibliography occupies the last five pages of this fascinating volume.—R. A. R.

"*Kempe's Engineer's Year-Book for* 1954." 59th edition. 2 vols., 8vo., illustrated. Volume One, pp. xiv + 1345; Volume Two, pp. x + 1413. London, 1954: Morgan Brothers (Publishers), Ltd. (Price 75*s*., two volumes in case)

As the publishers claim, "Kempe's" now covers practically every aspect of engineering, and many allied subjects. There are several new chapters, including one on powder metallurgy, written by H. W. Greenwood; this is a very valuable short treatment of the subject. A similar new entry is the chapter on atomic power, which contains much useful basic information. The whole work has been carefully revised, re-arranged, and printed in a new and clear type; as an encyclopaedia to engineering subjects it should easily retain the leading position it has held for so long.—J. P. S.

Lipson, H., and W. Cochran. "*The Determination of Crystal Structures*." (Volume III of "The Crystalline State," edited by Sir Lawrence Bragg). 8vo, pp. ix + 345. Illustrated. London, 1953: G. Bell and Sons, Ltd. (Price 50*s*.)

Many years have passed since the Braggs, father and son, first judged the time ripe for the production of a standard work in the English language on the crystalline state. The application of X-ray diffraction was rapidly changing the subject into a science in its own right, mainly under the stimulus of their own work. It was planned to produce a work in three volumes, the first a general survey by W.L. Bragg appearing in 1933. The publication of this new volume sees the task completed. Together with the two previous volumes this book forms a standard work which will always be of first importance to students in this field of study. Their comprehensive nature together with the clarity of exposition which all the authors have maintained and the excellent nature of the publications themselves have in fact ensured a standard work which it would be hard to better in any subject.

The delay in the appearance of the last two volumes has proved fortunate so far as the subject matter of this third volume is concerned. Since the early war years great advances in crystal structure determination have been made. Improved methods of measuring X-ray diffraction data have been combined with greater skill in the handling of the methods of analysis to produce structural information of a different order of magnitude and accuracy. This book brings the reader up to date in the principles underlying the latest techniques most successfully. The policy of providing plenty of examples throughout the book will be much appreciated and helps greatly when trying out a new method or when it has to be decided by which technique a particular problem should be tackled.

The first chapter on X-ray optics, in which all fundamental relationships between X-ray diffraction patterns and atomic arrangements are derived, will encourage the reader with modest mathmetical ability to continue. It is a measure of the success of the form of presentation that he should stay the course with little difficulty. The chapter on the determination and use of space groups includes a full account of the method of distinguishing between the "ambiguous" space groups by the statistical analysis of the intensity distribution among reflexions. Examples ensure that the reader will know exactly how to handle such data in practice. The three chapters on the calculation of structure factors, summation of Fourier series and trial-and-error methods will be particularly useful to the beginner. For the more experienced worker they provide a collection of information to which constant reference is made but which has otherwise to be sought in a variety of original papers. A good account of punched-card methods of calculation is included and the importance of absolute intensity measurements is emphasized.

There is a bias towards organic structures in the later chapters. The optical methods of Fourier synthesis and Fourier transforms are well described, but in their present form are really only applicable to these types of structures. In contrast, however, there are two excellent practical chapters on the use of the Patterson function and Fourier methods. These are widely used techniques, and, for example, confronted with an unsolved metal structure, the reader is most likely to find useful clues through the application of one of the Patterson methods. The last two chapters deal with direct methods of structure determination by means of structure factor inequalities and finally the accuracy of structure determination. As far as the reviewer is aware this is the first time that these two subjects have been fully covered in a book. The fact that attempts are now being made to apply direct methods to such unpromising material as metal structures indicate the scope of the advances we can expect in this technique. As the researcher so frequently finds inadequacies in his experimental data when he comes to the subject matter of the last chapter he could be well advised to use it as an aid to planning in his experimental work.

This book easily falls into the highly recommended category. The needs of both student and research worker are admirably met throughout.—A. D. I. Nicol.

Longden, Edward. "*Densening and Chilling in Foundry Work*." Ferrous and Non-Ferrous Casting. 8vo, pp. xi + 178. Illustrated. London, 1954: Charles Griffin and Co., Ltd. (Price 28*s*.)

This book should become an indispensible addition to the library of all those concerned with the casting of metals, and especially of those concerned with heavy casting. It has obviously been compiled with great care, and the amount of data given together with the large number of illustrations and photographs shows very clearly the author's mastery of the subject and his great experience in the making of castings in high-duty and general irons, carbon and alloy steels, malleable iron and non-ferrous alloys.

Whilst the majority of castings are produced nowadays without serious defects, there are problems of casting design which have persistently defied all purely metallurgical compositional solutions designed to eliminate certain types of fluid shrinkage and solid contraction defects. It is with this field that the artifice of "densening" and "chilling" to remove the hazards of defects in castings is concerned.

The value of the book lies in the fact that all the factors which influence the production of sound castings are dealt with progressively, and some excellent data and photographs support the argument. From metallurgical considerations through the characteristics of mould materials to observations on the various types of denseners and their use the book proceeds in a very logical manner, and is factual.

The more complicated question of shrinkage factors and distortion, and the use of camber on larger castings such as lathe beds are dealt with, and examples of the use of nomographs together with more normal methods of calculating the progressive shrinkage on steel rolls are extremely valuable.

The lessons which can be learnt from this book from the experience gained by the author can well be applied to the more recent methods of casting, such as the "C" shell process, and even to the precision investment process, even though the castings dealt with are a great deal smaller than those discussed in this book. The problems exist to the same degree, owing to the greater accuracy attempted by these later methods of casting.

Finally, the compilation of data such as the recommended analysis of castings, the recommended mould materials, types of denseners, and the effect of various methods of casting, such as centrifugal or permanent-mould casting, on the structure and physical properties of the alloys is extremely instructive.

This book is written by a specialist for specialists, and is a thoroughly comprehensive account of modern practice for heavy castings.—P. H. LAWRENCE.

MANCHESTER JOINT RESEARCH COUNCIL. "*Industry and Science.*" 8vo, pp. viii + 188. Manchester, 1954: Manchester University Press. (Price 12*s.* 6*d.*)

The Manchester Joint Research Council was established in 1944 as a joint venture of the University of Manchester and the Manchester Chamber of Commerce with the intention of strengthening the relations between science and industry; it did this in its early stages through a Liaison Service, and by the organisation of lectures and discussion meetings. In 1948 and 1949, however, the idea grew that it would be particularly useful to make a careful investigation of the use which was being made of scientific knowledge by the industries in the Manchester Area. This project received good moral and financial support, both locally and from the Department of Scientific and Industrial Research. It was decided to collect the evidence, not by written questionnaires, but by direct interviews with industrialists. The field was deliberately limited in scope by ignoring the clothing, building, coal-mining, gas, electricity and transport industries, and in scale by selecting firms employing not less than fifty people; in addition, very large firms of nation-wide connections were also omitted. The still very large remainder was sorted into four groups: "Modern," that is, manufacturing articles unknown a hundred years ago, of which the electrical engineering industry is a fair example, "Engineering", "Textile," and "Miscellaneous"—and of these, 225 were eventually visited. A further 70 would not agree to be investigated.

It was established with fair certainty that 77 of these undertook development from their own original research and new ideas, 42 relied on established principles and 26 merely adopted minor innovations or ideas already fully developed elsewhere, and that of the science graduates or holders of diplomas found to be employed in the firms investigated, 1021, or 71%, were employed in the first group of 77. A contrast to this is that, in a group of 25 firms, wherein scientific activity was limited to process control and routine testing, only 55 qualified men, or 4·3%, were found; 107 firms had no qualified staff at all.

A similar range of response was found to the use of research associations; 151 firms belonged to various associations, 14 of them to three or more, though themselves already well-staffed with scientific personnel and carrying out their own development programmes. Resistance to joining the appropriate research association came, to a very great extent, from firms who had no research departments of their own and moreover, employed very few scientific personnel; self-satisfaction, lack of ambition and the cost of the subscription were the chief reasons for holding back from the research association. From those firms that were members there was little criticism, the severest being that, perhaps, scientific problems were sometimes being tackled at the expense of technical ones; but it is far more serious that 23% of the firms approached should have been able to point out that there was no research association working on the problems of their branch of industry.

It is possible that this lack is met to some extent by consultation with University departments, with which 40% of the firms have active contact, but this is, in fact, greatest in the larger firms, and those already having a progressive scientific policy.

The report deals in similar detail with a number of other methods of obtaining and utilizing scientific advice, and the following general conclusions are reached: The ultimate responsibility for the use of scientific knowledge lies with management, and demands a scientific approach from it; many firms could well use new scientific and technical knowledge had they suitable staff, or even enough staff to review and appreciate the literature; where scientists and technologists are employed, they are not used wastefully; a need for more scientific staff is generally admitted, and in certain fields might eventually be hard to meet.

One clear conviction has forced itself upon the investigators, that more and better liaison between science and industry is a greater necessity than more and better science. In the words of the report, "The resources of science still untapped by industry are immense, and more and better bridges between industry and science, and greater mutual respect between the two worlds are the prime needs in Britain which the investigators think their enquiries have revealed."—J. P. S.

MANDLEBERG, J. H. "*Physical Chemistry Made Plain.*" An Aid for Intermediate Students and Others. 8vo, pp. viii + 287. London, 1952: Cleaver-Hume Press, Ltd. (Price 15*s.*)

The author has written this book expressly for students of post-matriculation and intermediate level whose mathematical equipment is below average. The method of treatment is to summarize the factual matter which can be found in the usual text-books and follow this with numerous worked examples. Thus, the emphasis is upon the solution of numerical problems, thereby presenting a clear picture of the significance of the usual mathematical formulæ, and a collection of worked examples of the type set in intermediate and scholarship examinations. In addition to its interest to students, this book should provide a welcome refresher course to readers whose elementary physical chemistry is a "thing of the past."

After an introduction to the use of book, Chapter II deals with the gas laws, vapour density, elementary kinetic theory, diffusion of gases and van der Waals' equation. A purely descriptive chapter on critical constants and the liquefaction of gases is followed by a brief description of eudiometric methods and the calculation of results obtained from them. A summary of the general properties of liquids and solids precedes five chapters in which the properties of solutions are described and illustrated with numerical examples on steam distillation, the distribution law, osmotic pressure, vapour pressure, elevation of boiling point, and depression of freezing point. The law of mass action and the velocity of reactions are dealt with in separate chapters, with calculations from experimentally observed data. The chapter on the phase rule is rather brief, whilst that on thermochemistry consists almost entirely of illustrations of the use of Hess's law. Chapter XVI on electrolysis and electrolytes is a valuable résumé of the facts and is amplified with numerous examples. The final chapter is an outline of atomic and nuclear structure and radioactivity, together with recent developments of topical interest. The appendix consists of a useful summary of mathematical methods, including elementary formulæ of mechanics and electricity. Unfortunately the important laws of thermodynamics have also been relegated to the appendix.

This book will be of value to students both for problems and for revision. The lucid style makes the text easy reading, although in parts the simplified, descriptive treatment of thermodynamic reasoning tends to confuse, whereas a mere statement of the facts could be accepted. Throughout the text there are numerous typescript errors in addition to those noted in the corrigenda, and these tend to be annoying but do not detract seriously from the value of this readable and very useful book.—N. S. CORNEY

NAISH, WILLIAM ARCHIBALD, JOHN EDWARD CLENNELL and VICTOR S. KINGSWOOD. "*Select Methods of Metallurgical Analysis.*" Second edition revised. 8vo, pp. xii + 660. Illustrated. London, 1953: Chapman and Hall, Ltd. (Price 75*s.*)

It is twenty-four years since the first and only previous edition of "Select Methods of Metallurgical Analysis" was published in 1929. A new edition may be considered long overdue. The quarter century which separates the two has witnessed more progressive change in the development and application of analytical techniques within the metallurgical industries than any previous equivalent period in history. It is therefore very proper, and indeed inevitable, that the new work should be largely a new construction rather than a reconstruction of the original—albeit the classical pattern of the first work has been well preserved in the new presentation.

In order to cover the tremendous scope required by the new edition, the authors have worked in conjunction with a panel of experts who have contributed or assisted in the compilation of specialist sections of the book. This is really the only way in which such a monumental task could be accomplished with any claim to authority, and, whilst the main purpose has been achieved, there are suggestions of the curate's egg in that some sections are better than others.

It is perhaps a pity that other editions have not been published at intermediate times, as this would have permitted a graduated evolution rather than a single bound into the new era. Perhaps this is one reason why the book is not as expressive of the new era as it might have been. During the last twelve years, thirty British Standard Methods have been issued for the analysis of iron and steel alone, but little use has been made of these, and it is regrettable that in one instance where such a method is utilized, namely, for phosphorus in steels containing tungsten and niobium, it is so seriously misrepresented as to be quite inadmissible for its declared purpose. No account whatever is taken of the vital residue treatment to reclaim phosphorus from the tungsten–niobium hydrolysis product.

The analysis of refractory materials does not appear to have changed very much since the days of Mellor, and it is disappointing to see methods for magnesite and chrome brick, for example, taken from a non-specialist text book published in 1902.

A new section deals, quite comprehensively, with modern physico-chemical methods, but there is an impression of detachment in that the principles enunciated therein are not implemented by their more frequent application in other sections of the book.

The book is divided into six parts. Part I covers the sampling of ores, alloys, etc., outlines methods of solution and separation which are of general rather than specific application, and concludes with a modernized scheme of qualitative analysis, the latter in particular is comprehensive and well done.

Part II is a large section (230 pages), approximately one-third of the book, and this gives a valuable classified selection of methods, with underlying chemical theory, for the determination of the elements.

Parts III, IV and V provide a comprehensive compendium of methods for the analysis of metallurgical materials, including commercial pure metals, light alloys, copper and zinc base alloys, white metals, platinum group metals, iron and steel and ferro-alloys, ores, slags, refractory materials, coal, and coke.

The concluding section, Part VI, surveys the physico-chemical field and deals with electrolytic, absorptiometric, spectrophotometric, polarographic, and spectrographic techniques.

In the main the methods are well chosen, but there are some exceptions, and there are too many errors of detail as well as some, unfortunately, of principle. For example, the method given for alumina in chrome brick would be completely invalidated by co-precipitation of the chromium. It is a shock to be told (p. 18) that chromium is not precipitated, along with iron, aluminium, etc., in the basic acetate separation, and in a method for vanadium in high-chromium steels we are instructed to wash a hydroxide precipitate with hydrochloric acid and in the next sentence to dissolve it in the same medium. It is obvious from the context that these are not inadvertent errors. Important omissions are the periodate method for manganese, and the nitroso-*R* salt method for cobalt.

There is also too much loose phraseology and cookery book jargon. Changes of tense within the same paragraph are common, and expressions such as " The solution is now boiled *when* 10g. sodium thiosulphate are added and the boiling continued keeping *bulk up*," or " Cool *slightly* to 50° C. and add ammonium hydroxide until *precipitate dissolves with difficulty* . . ." should find no place in a standard reference work.

In spite of these severe criticisms, the book has a useful niche to fill for the discerning analyst. It offers him, within the compass of a single volume, a readily available compendium of detailed method descriptions covering the whole vast field of metallurgical analysis, but the analyst must be discerning.—B. Bagshawe

Pilborough, Leslie. " *Applied Heat and Heat Engines.*" 8vo, pp. x + 328. Illustrated. London, 1954 : Butterworths Scientific Publications. (Price 35*s.*)

The author has set out to cover a very wide range in applied heat and heat engines ; he has tried to satisfy the requirements of students sitting for the third-year Ordinary National Certificate examination on the one hand and for the examination of the professional engineering institutions on the other. There is, regrettably, a certain unevenness of quality about the book ; some of it is very good, but elsewhere it is hardly up to standard. For instance, in the earlier part, dealing with elementary physics, Fahrenheit and Celsius temperatures are quoted without any apparent plan, and, further, conversion tables are not given ; again, the inclusion of steam tables would have been useful and would have supported the author's claim that the book was largely complete in itself.

The text is not everywhere so up to date as could be wished. Thus, reference is made to the adoption of the International Temperature Scale by the International Committee on Weights and Measures in 1927, but the Committee has met since, in 1948, and made important changes in the Temperature Scale. Again, the Féry radiation pyrometer has long been superceded, as has also the optical pyrometer using a milliammeter as the calibration yardstick. That the principles are clearly described is agreed, but they should be supported by really up-to-date equipment.

A couple of typographical errors have escaped attention : The thermocouple circuit in Fig. 24 would give the wrong e.m.f., as now drawn, and the relation " B.T.U./sq. ft./hr./°F.," used liberally, has no meaning.

Coming now to the later chapters, the author scores well ; his treatment of boilers, steam engines, internal combustion engines, steam turbines, and gas turbines is first rate. Many clearly worked-out examples are given, and the numerous sound and carefully contrived questions appended to each chapter should provide a good test of the student's understanding of what he has read in the text.

The get-up of the book is excellent ; the type face used is attractive, and the clarity of the diagrams is very commendable.—R. Mayorcas

Pomp, Anton. " *The Manufacture and Properties of Steel Wire* (Stahldraht)." Translated from the German by C. P. Bernhoeft. 8vo, pp. xiii + 358. Illustrated. London, 1954 : The Wire Industry, Ltd. (Price 84*s.*)

The second German edition of the later Professor Pomp's book, on which the translation is based, was reviewed in the *Journal* for July, 1953. It was then stated that the book had no equal as a comprehensive text on the fundamental principles and industrial practice in the manufacture of ferrous wire. For this reason its translation into English was eagerly awaited and the Publishers' enterprise in venturing into the unfamiliar and risky field of textbook publication was warmly applauded. Alas, instead of being a pleasure, the present review has turned out to be a most painful task.

The translation does not merely fail to match the original in quality ; it is downright bad. The " effort to follow the wording of the author " was mistaken ; inevitably, an almost literal translation from the German language sounds turgid. Here is a sample of his style : " The transversal force Q (Fig. 31) attacks the material to be drawn at the friction angle ξ perpendicular to the working surface of the drawing tool." In a technical book a poor style might perhaps be forgiven the translator, but in no circumstances can he be excused his slipshod and inconsistent translation of technical terms, without regard for accepted English equivalents ; here are a few examples : For ' percentage reduction of area (to fracture) ' the translator uses ' necking ' on p. 85, and ' necking point ' in Fig. 196 ; for ' boundary lubrication ' he uses ' surface greasing,' ' limit greasing,' ' limit friction,' all on p. 169 ; ' friction factor ' for ' coefficient of friction ' (p. 54) ; for ' shear ' he uses ' slip ' on p. 49 and 'shift ' in Fig. 84 ; ' pull ' for ' drawing force ' and ' die pull ' for ' die load ' in Fig. 77 ; the terms ' tensile ' and ' tensile strength ' are variously used for ' ultimate tensile stress '; ' torsion value,' ' twist capacity,' ' twist numbers ' for ' number of torsion '; and in Fig. 93 the fatigue limit in tension (*Zugschwellfestigkeit*) becomes ' yield limit ' in the title and ' maximum breaking load ' in the legend of the graph ! Some of these terms have been defined in British Standards (B.S.18), others can be found in reputable technical dictionaries ; the advice of specialists could have been sought on terms outside the translator's field. The translator's task is exacting, often tedious, rarely rewarding, but it is one which must not be lightly undertaken. This translator has done a disservice to the late Professor Pomp and to English and American students of the technology of wire drawing.

If, nevertheless, the reviewer strongly commends the book to those who cannot read the Germany original, it is because he is convinced of the outstanding and lasting value of its contents.

It was thoughtful of the Publishers to add illustrations of modern British-made machinery. Should they consider a revised edition, then perhaps they might be persuaded to change the units ; admittedly a conversion table is appended, but it is a tedious task to use the slide rule or multiplication table each time one wishes to make use of Professor Pomp's many excellent graphs.—J. G. WISTREICH

SACHS, G. "*Fundamentals of the Working of Metals.*" 8vo, pp. vii + 158. Illustrated. London, 1954 : Pergamon Press, Ltd. (Price 30*s.*)

This book is about the facts rather than the fundamentals of metal working. It is entirely descriptive, and little attempt is made to explain what is described. Of its six chapters, the first three are mainly concerned with the effects of metallurgical structure on ductility and resistance to deformation. Then follows a chapter entitled "Some General Concepts of Metal Forming," which consists of a definition of metal-working terms, a recital of the various types of fracture experienced in metal forming and a classification of metal-working processes into six basic kinds : Direct compression, tension, indirect compression or drawing, bending, contour-forming, and shearing. These are based, though how is not very clearly explained, on the four possible combinations of tensile and compressive principal stresses. In the next chapter examples of each of the six basic processes are described. The last chapter is taken up with various forms of progressive metal working ; nearly all the examples are taken from press-working processes, less than four pages being allotted to continuous rolling and wire-drawing.

The book, according to the dust cover, is intended for students and practical engineers. Anyone coming new to the subject will undoubtedly learn something about the scope of the subject from its chapters. But the author's purely qualitative approach is not likely to satisfy the more inquisitive reader who may want to form some idea of the relative importance of the things he reads about. The metallurgical chapters, for example, are copiously illustrated with graphs, but many of these are without scale, so that, although one may get an idea of how one variable affects another, there is no clue to the magnitude of these effects. On the other hand, some of the illustrations of press-worked parts in the later chapters are so plastered with dimensions which appear to have no relevance to the text that their clarity is impaired.

In spite of these limitations, the book does help to fill a serious gap in the still meagre bibliography of metal working. It is easy to read and the text is well printed, while what it lacks in the way of interpretation may actually stimulate the student to find it by further study of the subject elsewhere.—W. C. F. HESSENBERG

SEYBOLT, A. U., and J. E. BURKE. "*Procedures in Experimental Metallurgy.*" 8vo, pp. xi + 340. Illustrated. New York, 1953 : John Wiley and Sons, Inc.; London : Chapman and Hall, Ltd. (Price 56*s.*)

This is not exactly a common type of book. The nearest to it that the reviewer has seen previously is the collection of notes on experimental procedure and apparatus taken from the Journal of Scientific Instruments. The difference in the present volume is that the matter has all been written by the two authors and it has been chosen to suit a particular type of reader. In general, the authors have in mind the increasing number of physicists and chemists, who are engaged in metallurgical research, although the book will also be of value to certain types of research metallurgists, especially those dealing with the less common metals.

In brief, the authors deal with techniques involved in the preparation of metals for research. They have not attempted to discuss investigational methods, such as microscopy, X-ray diffraction, thermal analysis and mechanical testing, on which subjects, as they rightly point out, there are already numerous suitable works. The book, therefore, covers the preparation of pure metals and single crystals, the shaping of metals by melting and casting, by mechanical working and by powder metallurgy, and methods of obtaining, controlling and measuring high temperatures. In addition, the appropriate aspects of refractories, controlled atmospheres, vacuum systems and heat-treatment are described. All these subjects are treated on a scale suitable for modern research, and the treatment does contain some very useful, practical information and guidance. A not disconcerting number of references to recent papers is given at the end of each chapter, a few of these being from British sources, although the references to manufacturers of materials and equipment are, as far as can be seen, exclusively American. The text is illustrated by numerous line-drawings of high quality.

The book is distinctively written and the authors are clearly well informed in their subject ; they are especially to be commended for their enterprise in preparing this survey. The general production of the volume maintains the very high standard shown in general by American technical books.—A. R. BAILEY

"*Soft Magnetic Materials for Telecommunications.* A Symposium held at the Post Office Engineering Research Station in April, 1952. Edited by C. E. Richards and A. C. Lynch. 8vo, pp. viii + 346. Illustrated. London, 1953 : Pergamon Press, Ltd. (Price 63*s.*)

This book consists of a collection of papers which were the basis of an informal conference held in April 1952 at the Post Office Engineering Research Station. Most of these contributions, of which there are thirty-five in all, including eight by continental authors, describe the results of original research and cover a wide variety of themes. These include the modern theory of coercivity, permeability, and hysteresis loss, magnetic after effects and viscosity, and the properties and structure of ferromagnetic powders and of ferrites. Although the discussion of the papers, at the conference to which they were presented, was informal, there is a short written discussion to most of them together with a reply by the authors. The editors have materially assisted the reader by standardizing as far as possible the symbols used throughout the book.

Since it is a collection of advanced papers on particular themes and since it provides no general introduction to the subject of soft magnetic materials, the book cannot be regarded as a text book suitable for the use of students. It is, however, a reference book which will undoubtedly be of considerable value to workers in this field and it may be recommended to all who wish to have the modern developments in the diverse aspects of this subject neatly compressed in one volume.

A minor criticism, which perhaps arises from a complication of the editor's task by the wide range of themes which the papers cover, is that the order in which they are presented seems a little haphazard. Related subjects are not always to be found in juxtaposition. Fortunately, however, the index is sufficiently detailed to direct the reader adequately to his particular interests.—A. H. SULLY

VEREIN DEUTSCHER EISENHÜTTENLEUTE. "*Gemeinfassliche Darstellung des Eisenhüttenwesens.*" 16. Auflage. La. 8vo, pp. ix + 581. Illustrated. Düsseldorf, 1953 : Verlag Stahleisen m.b.H. (Price DM 38.50)

This excellently produced and profusely illustrated volume lives up to its title ; it is indeed a comprehensive presentation of the whole technical and economic field of the iron and steel industry, its present status, and how it has developed. With such a broad thesis as this, it is inevitable that much condensation has been needed and this appears to be the cause of some surprising omissions. The book is written from a German viewpoint, which tends to make it somewhat biassed, but if this is borne in mind it should prove to be a valuable reference for those having to do in any way with iron and steel.

The first part, almost one half of the book, deals with the production of iron, steel and semi-finished products. The treatment is logical ; after a brief historical introduction, which includes a useful table of dates at which important innovations were introduced, the processes of iron and steel making are reviewed. The first chapter proper deals with raw materials. It gives a succinct account of the geographical distribution of the various kinds of iron and manganese ores and their preparation, and a detailed description of the manufacture of coke and the recovery and utilization of the by-products. There is a very short section on refractories, but no mention of that important constituent of the blast-furnace burden, lime.

The next chapter, devoted to the blast-furnace, is in general excellent, and the design and operation of the furnace and its ancillaries, the composition of the burden, the nature and uses of slag, and the properties of the metal are fully described. Reference is made to other smelting methods, among which may be mentioned the electric furnace, the Edwin, the Basset, and the low-shaft furnace processes. The production of ferro-alloys is covered in less than one page, with only the barest reference to the methods employed. To anyone wanting to know about ferro-alloy manufacture this is quite inadequate, whereas to the general reader, the page is virtually meaningless. The composition of blast-furnace gas and its cleaning are described but briefly.

In the chapter dealing with steelmaking, most space is devoted, naturally, to the converter and the open-hearth furnace. The construction and operation of these units is very well described ; shorter sections within the chapter discuss, somewhat superficially, production in puddling, electric arc, induction, and carbon-rod furnaces. In a book which claims to review the present status of the steel industry, it is surprising that the only references to oxygen concern its use for enriching air to the converter and the blast-furnace. No mention is made of the pre-refining of iron or the new Linz-Donawitz process for steelmaking.

The chapter on the shaping of iron and steel opens with a section on casting and then passes to forging, hot rolling and drop forging. These sections give a satisfactory picture of these important stages in the making of primary products ; cold-rolling of sheets and strip and the drawing of wire and tube bring the account to a close. Here again there is an unevenness of treatment. For example, pilger rolling of tube is illustrated by photograph and diagram showing clearly how the method works, yet under wire-drawing, there are merely three photographs giving general views of a drawing shop and not one of a drawing machine nor any indication of what a die looks like or what it does.

The last section on iron and steel production is an extremely useful one and indicates textually and by flow diagrams the functions and inter-relations of the component parts of an integrated steelworks, comprising ore and coal yards, coke-ovens, blast-furnaces, Bessemer converters and open-hearth furnaces, rolling mills, and forging shops, etc. The final chapter in Part I deals with the properties and testing of iron and steel. This is highly condensed, but gives a useful survey of the constituents of solid ferrous alloys, including photomicrographs of typical structures, the effect of heat-treatment, the properties required for given applications and the choice of chemical composition to ensure them. The section on testing is very short.

The second part of the book would appear to be the more useful to those in the iron and steel industry or those concerned with the economics thereof. It starts with a chapter which tabulates the coal, coke, iron and manganese ore, pig iron, crude and semi-finished steel, oil, electricity and gas production in all countries of the world, mostly for the years 1900–1952. There follow sections dealing individually with the iron economy and raw material position of all steel-producing countries.

The chapters which follow will appeal, in the first instance, to the German reader, but are valuable to others nevertheless, since they report matters which have world-wide repercussions. The organization of technical and financial matters and the place of the German iron and steel industry within the industrial framework of Germany are discussed, and a very extensive chapter indicates the nature, functions, and responsibilities of the European Coal and Steel Community. The final sections are concerned with the ore, iron and scrap trades, the past and present prices of steel and raw materials, the uses of steel, the importance of rail, water, and road transport for the industry, and an index of the blast-furnaces, steelworks, and rolling mills in the Federal Republic and West Berlin.

J. PEARSON

WANG, CHI-TEH. "*Applied Elasticity.*" 8vo, pp. ix + 357. Illustrated. New York, Toronto, London, 1953 : McGraw-Hill Book Co., Inc. (Price 57*s.* 6*d.*)

This volume must be acknowledged at once as a valuable and very welcome addition to the literature. There are approximately 350 pages, of which 75 are devoted to the discussion and development of the fundamental equations of elasticity ; a further 75 are used to introduce in appropriate places different branches of pure and applied mathematics, and to derive results which are of importance in the formulation and solution of problems ; the remainder of the text demonstrates the diversity of their possible applications, whilst pertinent examples for the reader are included at suitable points.

Whilst Dr. Wang has developed the subject for media which are continuous, isotropic, and homogeneous, he has mentioned early in his exposition the more complex behaviour of aeolotropic materials, such as woods and crystals, and the statistical anisotropy of heavily worked polycrystalline aggregates. The existence of this complexity is a fact with which the modern student should certainly be acquainted, even though he may be most unlikely to grapple personally with the problems to which it gives rise.

Chapter 6 upon the theory of finite differences and relaxation methods deserves honourable mention, although both this chapter and the subsequent one on energy principles and variational methods, would appear in better sequence if they were immediately antecedent to the treatment of buckling problems by numerical means ; the chapters on solutions by means of complex variables and the bending and compression of bars might reasonably precede the development of approximation processes.

The appearance of some differential geometry before the treatment of plates and shells is to be applauded, though both this introduction and that to the theory of the complex variable, whilst being models of clarity, are very condensed ; they will certainly cause high mental stress concentrations for most students who have not previously received some instruction in the two subjects. On the other hand, they are excellent as reminders of the knowledge which will be needed at the finger tips.

Although the book is not specialized, the student of aircraft structures will perhaps be more grateful for this volume than other structural engineers, particularly since it includes between two covers, for him, subject matter for which three or four references were hitherto necessary.

The author has chosen to deal with statical problems only ; presumably he has felt that justice could not be done to dynamical problems without greatly increasing the length of the text with a consequent rise in cost, and his decision may well be the correct one in order that the volume may not be found only in reference libraries. Perhaps we may hope for as good a book on these latter problems sometime in the future.

The standard of the typography, diagrams, and binding is of the high quality which the McGraw Hill Book Company has established during recent years.

M. J. P. MUSGRAVE

WEIHRICH, ROBERT. "*Die chemische Analyse in der Stahlindustrie.*" Bearbeitet von Prof. Dr. August Winkel. Vierte umgearbeitete und erweitete Auflage. (Die chemische Analyse, Bd. 31.) La. 8vo, pp. viii + 223. Illustrated. Stuttgart, 1954 : Ferdinand Enke Verlag. (Price DM 32.–)

This is a revised and enlarged edition of a book which is reputed to be widely used in the German steel industry. Being unacquainted with earlier editions, the reviewer is unable to judge how far this book has been altered or improved by Professor Winkel's revision. The present edition, which is well printed on good paper and strongly bound, is divided into eleven sections : (1) Sampling ; (2) Qualitative Testing ; (3) Gravimetric and Volumetric Analysis of Steel, Ferro-Alloys and Ores ; (4) Potientiometric Methods ; (5) Colorimetric (frequently misspelt "*kalorimetrischen*") Methods ; (6) Polarography ; (7) Micro-Analysis ; (8) Recovery of Reagents (silver, iodine, and ammonium molybdate) ; (9) Emission Spectrography (only an indication of the procedure) ; (10) Tables ; and (11) Bibliography. These sections are subdivided on a decimal system.

Tradition plays a larger part in the selection and treatment of methods in steel analysis than it does in most branches of analytical chemistry, and traditions differ in different countries ; thus one should not be surprised to find one's own standard methods not given at all—for example, the sodium bismuthate method for manganese. But even so it must be said that in the present work a num-

ber of the older methods are out of date and a number of the modern ones missing or inadequately described. In the determination of nickel in the presence of cobalt (p. 52) rather more help is needed than to say that nickel is precipitated with excess of dimethylglyoxime. There is no mention in the section on steel of any organic aids for the precipitation of tungsten, nor of alpha-benzoin oxime as a reagent for molybdenum ; and one had hoped that attempts to precipitate molybdenum by passing H_2S through an acid solution, with or without a pressure bottle, had now been abandoned. The use of perchloric acid (p. 114) is not recommended, owing to the danger of explosions (English chemists seem to stand between the German and the American in their readiness to use perchloric acid), but frequent use is made of the ether separation, with its attendant fire risk. Tantalum and niobium are often mentioned as interfering elements, but no method is given for their determination either in steel or in ferro-alloys (they appear however in a short list of chemical factors on p. 208). Boron is not mentioned. Perhaps these, together with cerium, are among the " rare alloying constituents " which Professor Winkel says in his preface he has omitted from this edition.

In the section on ferro-alloys, it is stated (p. 119) that ferrotungsten and tungsten metal are insoluble in acid. They are, of course, soluble in $HF–HNO_3$, and thus the troublesome mercurous nitrate precipitation can be avoided. Under ferrovanadium there is no mention of the convenient ferrous sulphate titration of 5-valent vanadium, which is well known in Germany as the " Lang-Kurtz " method, and forms the basis of B.S. 1121, Part 25.

In the photometric determination of tungsten (p. 183) $TiCl_3$ is given as an alternative, not as addition, to $SnCl_2$, but there are no directions for its use, and its action in speeding up colour-formation and reducing molybdenum interference is not pointed out.

It is hoped that the above is not unduly critical. But the reviewer does not feel that this book fills any gap in existing literature in a field in which the English worker is already very well served.—G. M. HOLMES.

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